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PROPANE UTILIZATION IN THE AUTOMOTIVE FIELD THROUGH ENGINE OPTIMIZATION, DUAL FUEL SYSTEMS AND PROPANE BLENDS

PREPARED FOR:

Efficiency and Alternative Energy Technology Branch
Energy, Mines and Resources Canada
Ottawa, Ont.
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EXECUTIVE SUMMARY

This final report has been prepared by Chrysler Canada Ltd. for Energy, Mines and Resources Canada and the Province of Ontario under DSS Contract No. 23SQ.23216-4-6124X, entitled Propane Utilization in the Automotive Field through Engine Optimization, Dual Fuel Systems and Propane Blends.

Six separate reports have been completed, and each serves as a section of this final report. They are entitled the following:

- The Development of an Optimized Dual-Fuel Gasoline Propane Passenger Car
- Optimization of Compression Ratio for a 2.5-L Propane-Fueled Engine
- The Development of a Computer-Controlled Propane Fuel Metering System
- Alternatives for Advanced Propane Fuel Metering Systems
- An Evaluation of Valve and Valve Seat Materials for Propane-Fueled Vehicles
- Mixed-Phase Withdrawal for Cold Starting of Propane Vehicles

RÉSUMÉ

Ce rapport définitif a été préparé par Chrysler Canada Ltd. pour le compte du ministère de l'Énergie, des Mines et des Ressources et la province de l'Ontario en vertu du contrat n° 23SQ.23216-4-6124X. Le rapport s'intitule: L'utilisation du propane dans le domaine automobile par l'optimisation du moteur, des circuits d'alimentation à deux carburants et des mélanges au propane.

Six rapports distincts ont été préparés et ont servi à constituer ce rapport final. Ils sont:

- La mise au point d'une voiture optimisée avec système à deux carburants : l'essence et le propane
- L'optimisation du rapport de compression pour un moteur de 2,5 L alimenté au propane
- La mise au point d'un système de dosage de propane réglé par ordinateur
- Différents systèmes perfectionnés de dosage de propane
- L'évaluation des matières dont sont composés les soupapes et sièges de soupapes dans les véhicules au propane
- L'extraction en phase mixte pour le démarrage à froid des véhicules alimentés au propane

SECTION I

THE DEVELOPMENT OF AN OPTIMIZED DUAL-FUEL GASOLINE-PROPANE PASSENGER CAR

BY
CHRYSLER CANADA LTD.

AUGUST, 1989

ABSTRACT

A developmental program was performed to develop a vehicle to optimize operation on both gasoline and propane fuels. Systems were developed to provide optimum performance, fuel economy and emissions on both fuels. Developments were evaluated with engine and chassis dynamometer testing and on-road evaluations.

A dual-fuel system increased fuel consumption on gasoline by 7.8%. Operation on propane improved energy efficiency by 1.4% as compared to gasoline. Emission requirements were met on both fuels.

RÉSUMÉ

Le présent projet a été réalisé dans le but de mettre au point un véhicule ayant une consommation optimale de carburants pour l'essence et le propane. Les systèmes sont mis au point en visant une performance optimale, des économies de carburants et la réduction des émissions. Les systèmes ont été mis à l'essai avec engins et dynamomètre de chassis ainsi qu'évalués sur la route.

Le système à deux carburants a entrainé l'augmentation de la consommation de l'essence par un facteur de 7,8 %. L'efficacité énergétique de la voiture fonctionnant au propane a augmenté de 1,4 % comparativement à celle de la même voiture fonctionnant uniquement à l'essence. Les normes d'émission pour les deux carburants ont été respectées.

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1. INTRODUCTION

The purpose of this study is to develop a dual-fuel vehicle to overcome the present dual-fuel vehicle disadvantages in emissions, fuel economy, power, and driveability, through the use of advanced engine controls.

Aftermarket dual-fuel systems available today often make compromises in these areas: Changes made to the engine in order to install propane fuel systems often may result in non-compliance with regard to engine emissions during operation on gasoline, and needlessly high emissions on propane. Control hardware lacks a smooth transition between operation on gasoline and propane, and power and driveability penalties usually exist. For these reasons current dual-fuel systems provide fuel economy that is not as good as when the vehicle is built to optimize for either fuel alone.

Through the combination of modern fuel injection gasoline technology and the best available propane fuel system, a single point, fuel injected, front wheel drive, four cylinder vehicle has been designed and prototyped that minimizes the disadvantages of present day dual-fuel systems.

The intake system has been developed for optimum performance on both fuels. Dual logic modules provide spark advance schedules for both fuels and the gasoline fuel calibration is not affected during propane mode operation. All emissions equipment remains fully functional during gasoline mode operation. Smooth fuel mode change-over was accomplished primarily through a propane pressure sensing device.

Developmental testing imcludes: engine dynamometer testing for power and air-fuel distribution, on-road driveability analysis, and fuel economy and emissions testing using a chassis dynamometer with constant volume emissions sampling.

2. TEST EQUIPMENT

2.1 Test Vehicle

The base vehicle was a 1986 Reliant L.E., 4 door sedan. A 2.2L four cylinder, electronic throttle body fuel injected engine, coupled to a 3 speed automatic transmission. The emissions hardware includes EGR, aspirator, and oxidation catalyst (Figure 1).

2.2 Engine Dynamometers

A 275 hp Eaton eddy current engine dynamometer (No. 1014 - 1RW16) was used in the development of the carburetion and air induction systems.

2.3 Chassis Dynamometers

Emissions and Fuel Economy comparisons were performed using the Constant Volume Sampling test method on a Clayton CT150 chassis dynamometer using Beckman exhaust analyzers.

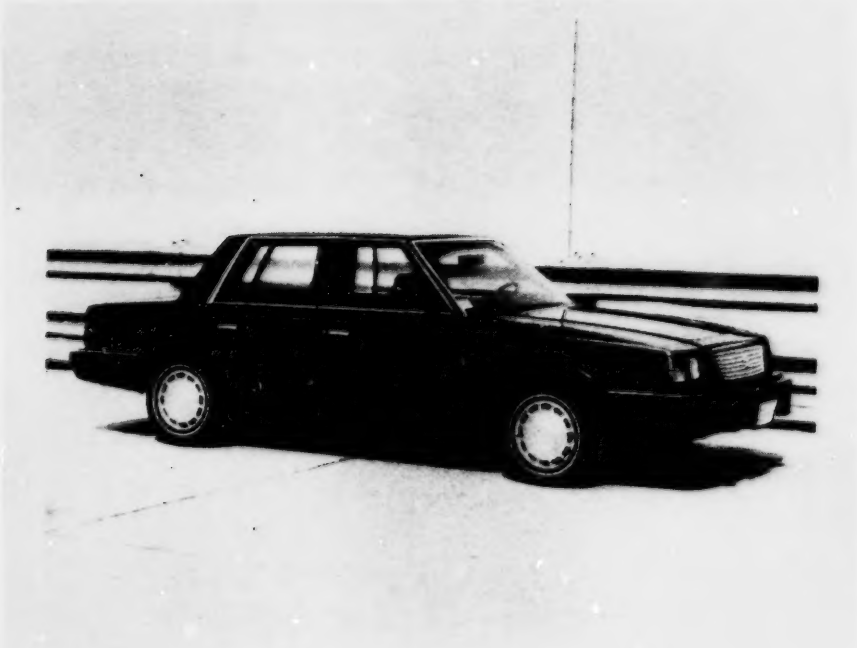

Figure 1 Base 1986 Reliant L.E., 4 door sedan.

3. SYSTEM DEVELOPMENT

3.1 Design Objectives

The ojective of this development program was to overcome the typical problems encountered with todays aftermarket dual-fuel conversions. Many such systems are based on add on components to the base gasoline configuration. This often leads to a vehicle that has not been optimized for either fuel.

To eliminate sacrifices in performance, durability and emissions encountered with most dual-fuel vehicles the following design criteria were identified:

- Provide optimized spark timing for both fuels.
- Eliminate adaptive memory fuel control problems.
- Retain the fresh air intake system.
- Minimize the air inlet restriction.
- Maintain heated intake air and intake manifold for gasoline.
- Design the dual-fuel system to provide smooth transition between fuels for all modes of vehicle operation.
- A full range fuel tank is to be provided in addition to the standard gasoline fuel tank with minimal compromise in luggage space or refuelling capability.
- Maintain proper operation of all gasoline emission control devices and ensure emissions are within regulated standards.

3.2 Fuel System

3.2.1 Fuel Tank

A custom designed 68 litre propane fuel tank bolts to the vehicle underbody, behind the rear axle. The tank capacity matches that of the standard gasoline fuel tank, effectively doubling the range of the base vehicle (Figure 2).

3.2.2 Fuel Filler System

Located rearward to the gasoline fuel filler door is an identical filler door containing the propane remote fuel fill valve and the fixed liquid level gauge bleeder. This arrangement provides easy access as well as a unobtrusive appearance (Figure 3).

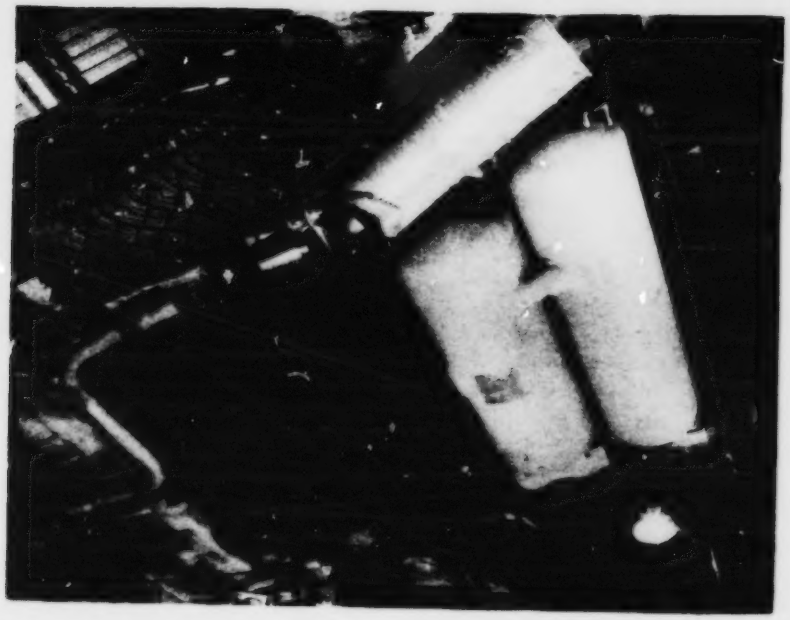

Figure 2 Standard Gasoline Fuel Tank and Custom Propane Fuel Tank Mounting Arrangement

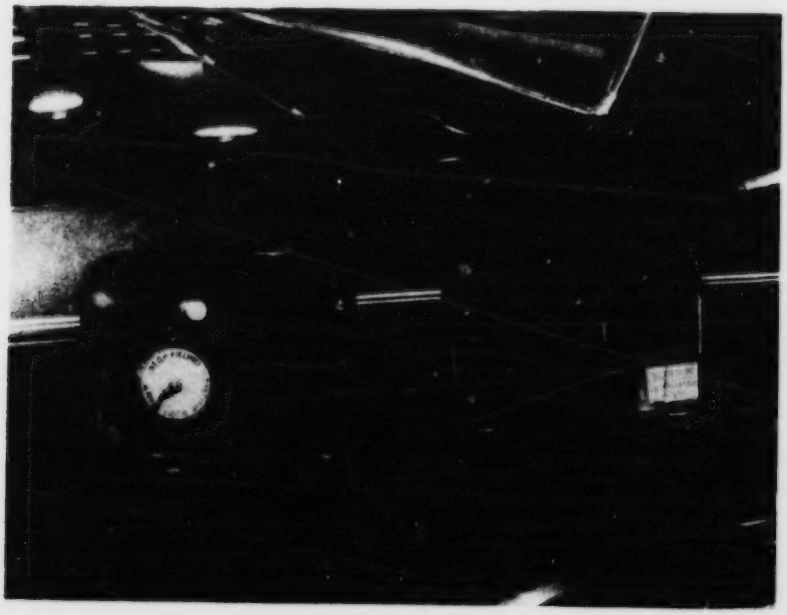

Figure 3 Gasoline and Propane Fuel Fill System

3.2.3 Fuel Tank - Gauge Readings

This circuit is best described by the use of the schematic in Figure 9 that follows. The mode of operation controls a switching relay which directs the fuel gauge input to either the gasoline of propane sending units.

3.2.4 Fuel Lines

The double wall, wire wrapped propane fuel line follows the path of the production gasoline fuel and vapour lines and are bundled together for the length of the underbody (Figure 4).

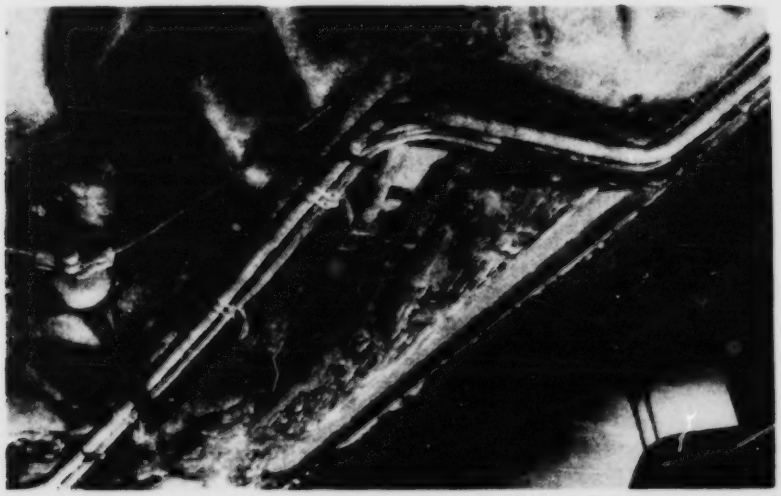

Figure 4 Gasoline and Propane Fuel Line Bundle

3.3 Engine System

3.3.1 Heated Intake Manifold

Most production carbureted and throttle body injected gasoline engines heat the intake manifold to aid in vaporizing the fuel. Because propane is pre-vaporized in a vaporizer/regulator, propane engines do not require additional heat input in the intake manifold which would only serve to decrease its density and lower the volumetric efficiency. Also heating the intake charge will lower the KLSA (Knock Limited Spark Advance). For these reasons the intake manifold should not be heated when propane is used as the fuel. Most dual-fuel systems continue to use a heat crossover or hot spot to maintain good performance with gasoline, but this is only done at the expense of diminished power and performance with propane. Since a heated intake is desirable for gasoline operation and not for propane operation a switching system was developed to provide heat to the intake manifold for gasoline operation only.

In Chrysler four-cylinder throttle body injected gasoline vehicles a portion of the engine coolant is routed from the cylinder head to the intake manifold to provide manifold heating. This coolant then enters a four way valve and goes either to the heater and then to the water pump inlet, or directly to the water pump inlet, depending upon the position of the heater controls.

For dual-fuel operation an additional four way valve was installed in the intake manifold/heater coolant loop. While operating on gasoline, coolant flows from the cylinder head to the new four way valve, into the intake manifold, and then to the heater control valve. For propane operation, the coolant flows from the cylinder head to the new four way valve, and then directly to the heater control valve, bypassing the intake manifold. It was necessary to replace the manifold vacuum operated actuator of the production four way valve with a DC servo motor, since there is not enough vacuum available to operate the valve at WOT and heavy throttle openings.

3.3.2 Heated Inlet Air System

Inlet air heating is required for gasoline fuelled vehicles to aid in fuel vaporization and to prevent throttle blade icing. Propane, however, does not require inlet air heating because, unlike gasoline, it is fully vaporized when it enters the mixer. Consequently the following method was used for switching the heated air system "on" for gasoline and "off" for propane.

A manifold vacuum-actuated, heated air door was installed in the air cleaner housing to regulate the flow of air from an exhaust stove and duct. The vacuum signal was modulated by a temperature sensor/vacuum bleed valve in the inlet air stream. By bleeding off the vacuum signal in a continuously varying manner, the heated air door was either fully closed above an air temperature of 60°C, partially open from 46°C to 60°C, or fully open below 46°C.

For propane operation, a solenoid was added in the heated air door vacuum line and was energized to shut off the vacuum signal, thus closing the heated air door and blocking the flow of air from the stove duct into the air cleaner housing.

3.3.3 Start Assist Solenoid

The Start Assist Solenoid is used to enrich the propane fuel mixture during start-up. This operation is not required during gasoline mode, and is disabled by a "normally open" relay activated when in the propane mode of operation. See Figure 9.

3.3.4 Fuel Injector Control

The initial attempt at disabling the fuel injector by a "normally open" relay proved unacceptable. When the relay was activated by switching from propane mode to gasoline mode at idle, the overlap of fuels caused by the instantaneous on of the fuel injector, created significant overfuelling and rough idle with a slow recovery. In the opposite mode of operation, the instantaneous off of the injector and the time delay for the propane vapour to reach the combustion chamber resulted in a die-out. These characteristics of operation also produced very noticeable hesitations during part throttle , wide open throttle and cruise conditions.

To overcome these problems, a low pressure switch was installed in the propane high pressure fuel supply line located between the fuelock and vaporizer. When the mode of operation is switched from propane to gasoline, the following events occur. The propane fuel supply is shut-off via the fuelock. The engine continues to run on propane, and in so doing, the fuel line pressure gradually reduces. The injector control was changed to a low pressure switch and a "normally closed" relay. When the control point of the switch is reached (13.8 KPa), the circuit opens, the relay closes, and the injector begins operation. In the opposite mode, from gasoline to propane, the injector continues to operate after switching, until the propane fuel line pressure exceeds the control point of the switch. This simple feed-back circuit displayed large improvements over the previous method.

3.3.5 Inlet Air System

The inlet air system was left intact to retain the benefits of fresh air intake, PCV plumbing, and the heated intake air feature of the production system. The propane mixing chamber was added in-line with the existing system and a low restriction air filter and prototype housing substituted for the base vehicle air filter and housing (Figure 5).

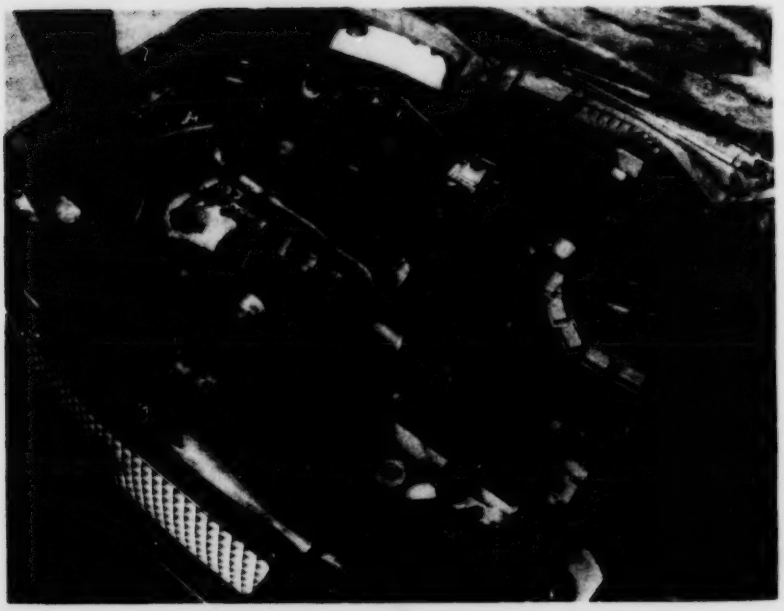

Figure 5 Dual-Fuel Air Induction System.

3.3.7 Dual Spark Control

The base engine of the development vehicle has a single point throttle-body fuel injection system. The engine controller for the 1986 model year is composed of a logic module and a power module. The logic module contains the microprocessor and peripherals, the system memory, the interface circuits for the engine sensors, and the driver circuits for relays, solenoids and automatic-idle-speed motor. The power module houses the power supply, the auto-shut-down relay and the driver circuits for the ignition coil, the fuel injector and the alternator coil.

The ignition timing requirements are quite different between propane and gasoline. The ignition timing schedules shown in Figure 6 and Figure 7 depict the optimized timing requirements for a stabilized engine at normal operating temperature. When operating on gasoline, separate part throttle spark advance schedules are used at colder temperatures. At idle, the spark advance is used to fine tune the idle speed control.

In order to deliver optimized ignition timing for each fuel an additional logic module dedicated to propane timing computation was used. Slight modifications were made to the sensor interface circuits in the propane logic module to avoid contaminating the sensor signals. Both the gasoline and propane logic modules monitor the usual engine sensors and compute the optimum spark advance timings simultaneously as shown in Figure 8. The ignition command signal from each logic module is fed to a logic switching circuit (as shown in Figure 10). In sensing the state of the fuel selection switch located at the instrument panel, the switching circuit latches onto the correct ignition command signal and outputs it to the power module. The driver circuit in the power module switches the ignition coil to deliver the sparks according to the incoming ignition command signal. The switching circuit is built around a flip-flop. In using a simple logic circuit such as this for signal switching, noises generated by mechanical switch contact bounce can be eliminated.

In addition to computing ignition timing, the propane logic module also controls the start-assist solenoid valve for engine starting. This feature provides the standard fuel priming and deflooding control through the start assist solenoid valve. When propane is used, the solenoid is energized during cranking to allow an extra amount of fuel to enter the carburetor to aid engine starting. For deflooding, the solenoid valve is disabled when the throttle valve opening exceeds a preset position.

Almost all gasoline injection systems use some form of feedback control system to adjust the air fuel ratio around the stoichiometric ratio with the signal from an exhaust oxgyen sensor. Chrysler's feedback control system makes use of the adaptive (non-volatile) memory in the logic module to store long term correction values for the fuel injector pulse widths. When the engine is stabilized at normal operating temperatures, these correction values are updated according to how often and in which direction the pulse widths are adjusted in response to the feedback signal from the oxygen sensor. These correction values are used subsequently in the injector pulse width equation at all times to compensate for any drift away from the stoichometric condition.

However, if the oxygen sensor is left connected to the system when operating on propane, the leaner condition perceived by the oxygen sensor leads the adaptive memory to update to faulty

values. When the engine is switched back to operate on gasoline, these faulty adaptive memory values can enrich the fuel by as much as 25 % until conditions enabling feedback control are met. This condition can produce unacceptably high amount of hydrocarbon and carbon monoxide in the exhaust and poor fuel economy.

The gasoline logic module was modified to maintain adaptive memory contents during propane operation to avoid this problem.

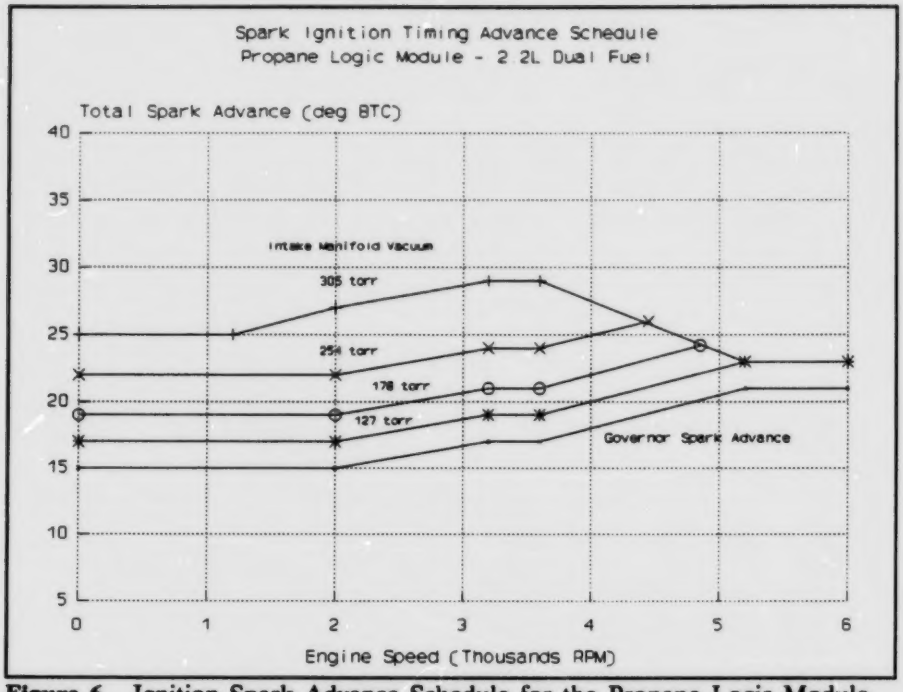

Figure 6 Ignition Spark Advance Schedule for the Propane Logic Module.

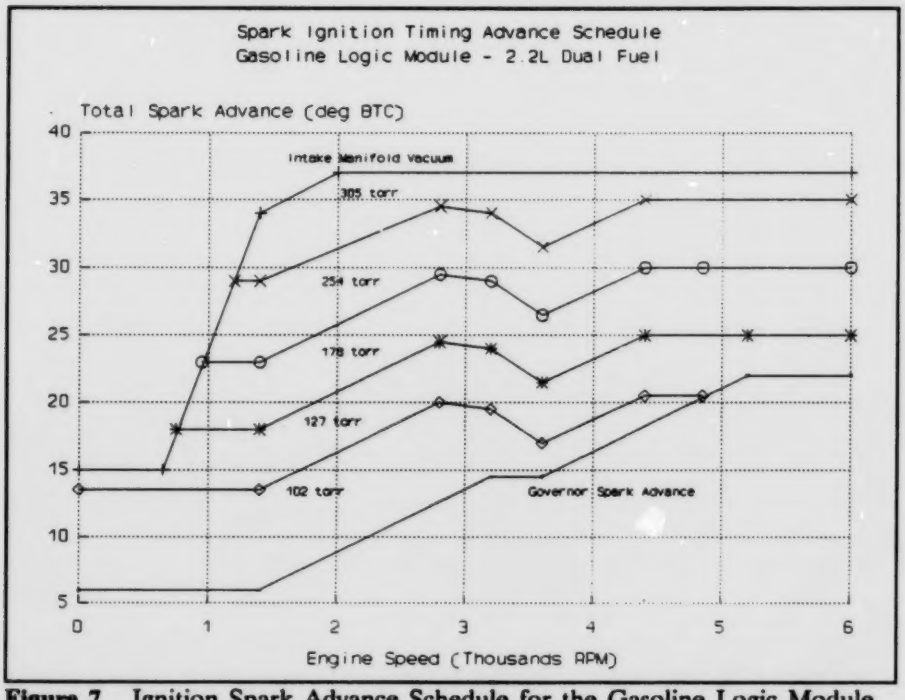

Figure 7 Ignition Spark Advance Schedule for the Gasoline Logic Module.

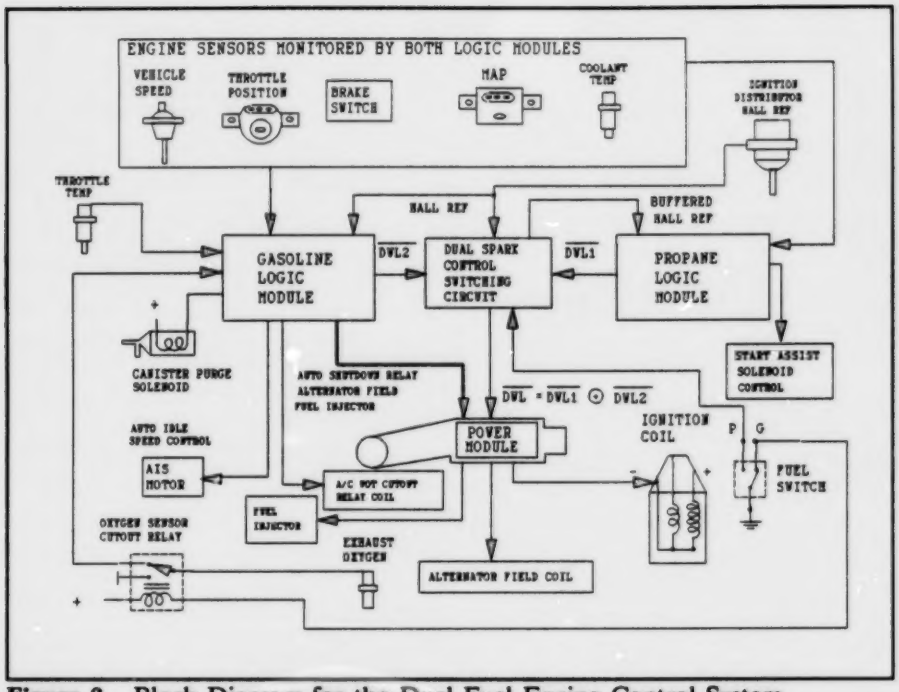

Figure 8 Block Diagram for the Dual Fuel Engine Control System.

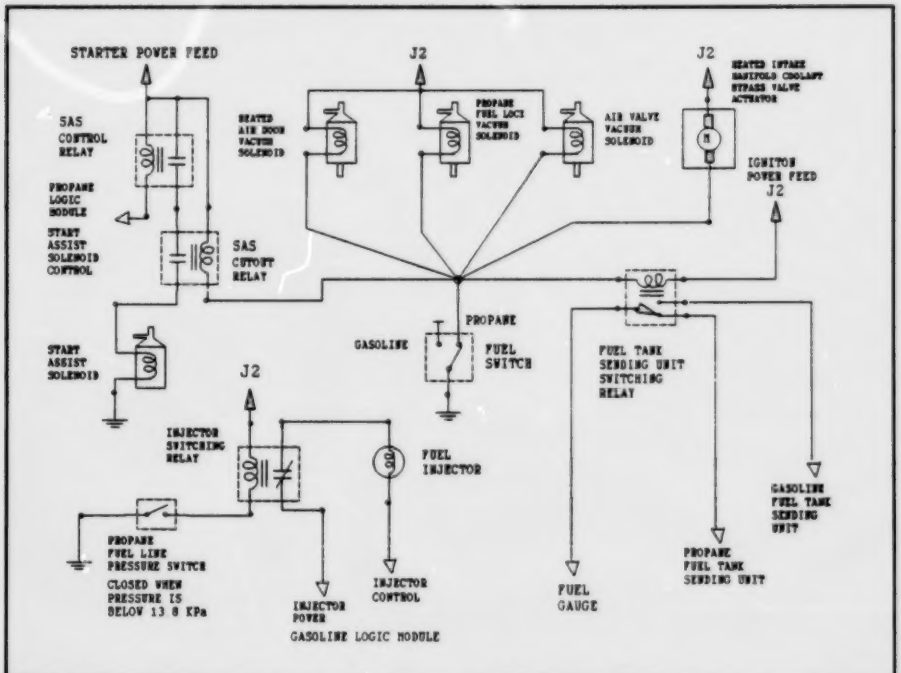

Figure 9 Wiring Diagram for the Dual Fuel Spark Control Switching Circuit.

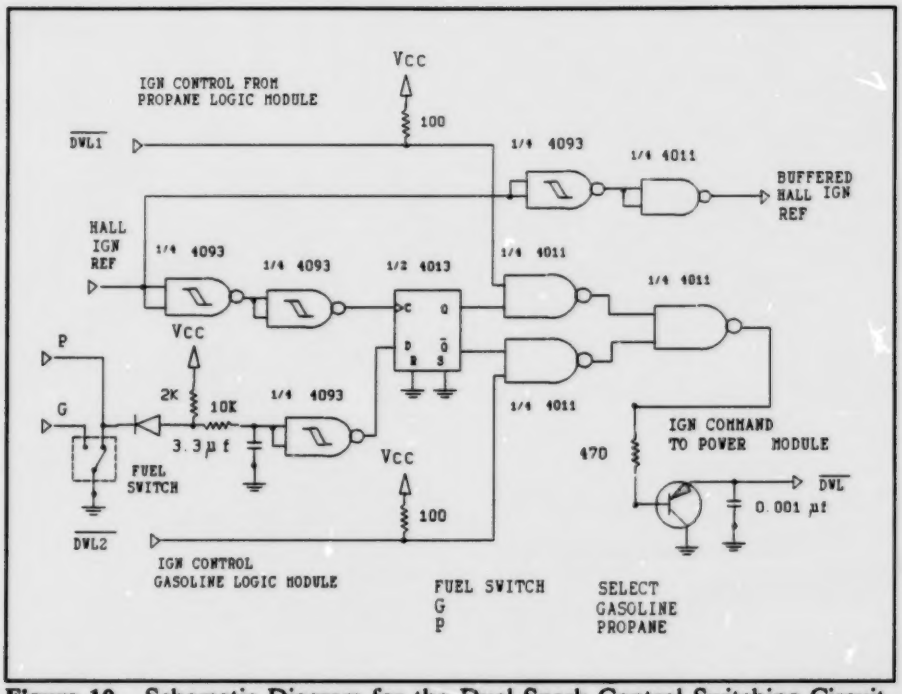

Figure 10 Schematic Diagram for the Dual Spark Control Switching Circuit.

4. PERFORMANCE EVALUATION

To evaluate performance losses as a result of modifications made to the induction system, a back to back comparison was made of the '86 Production Gasoline air induction system to the Dual-Fuel air induction system. A 2.5L 4 cylinder gasoline dyno engine supplied horsepower, torque, manifold pressure and air distribution data.

The results are displayed graphically in Figure 11. Losses of 7.1 and 2.3% respectively in corrected brake horsepower and corrected torque are explained by the air restriction and air distribution spread of the dual-fuel air induction system.

Through the development of low restriction air induction components and an added a feature to raise the propane mixer air valve to its maximum position during gasoline mode of operation, moderate improvements were obtained. A prototype throttle body injector to propane mixer adapter was developed with an internal screen to improve air-fuel distibution.

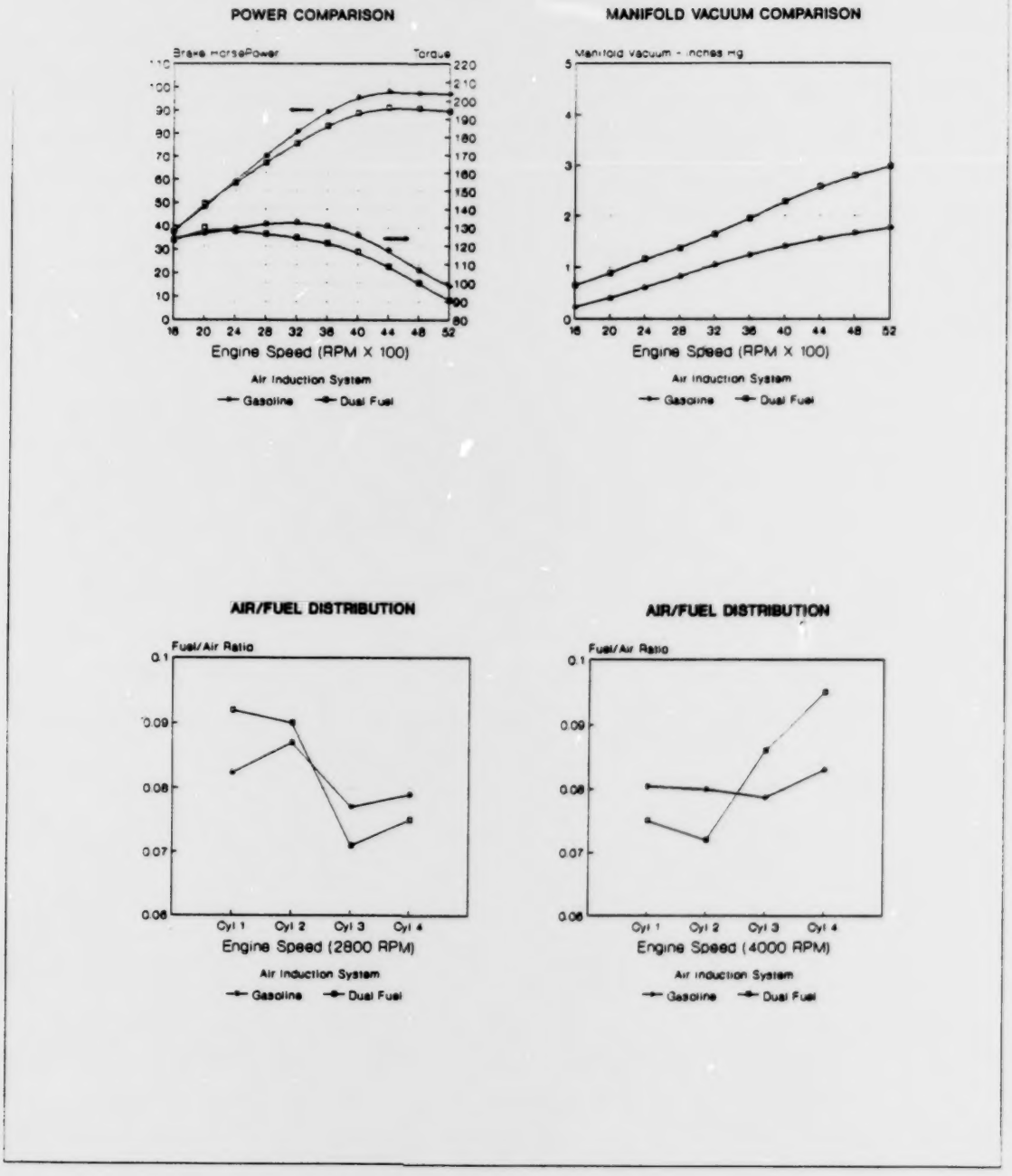

Figure 11 Performance Evaluation and Air/Fuel Distribution

5. DRIVEABILITY EVALUATION

The "SID" (Start, Idle, Drive) rating system has been used by various Corporate activities since its development in June, 1975. Vehicles are evaluated for several functions under various vehicle conditions, such as, but not limited to:

Functions:	Engine Starting
	Idle Rating
	Car in Motion - Driveability
	Performance
	Spark Knock
	Stalls
Conditions:	Cold
	During Warm-Up
	Warmed Up
	After Hot Soak
	After Partial Cool-Down

A 1 to 9 (9 being best) numerical rating system is used for rating the functions. The rating number is intended to represent the driver satisfaction level. Downgrade for stalling is reflected in the appropriate S.I.D. function.

The basic Engineering Driveability objective is to obtain S.I.D. rating values of 8.5, on average, for all Start conditions and a 7.0, on average, for all Idle and Drive conditions. Vehicles maintaining a S.I.D. rating equal to or higher than a 7.5, on average, for all Start conditions and a 6.0, on average, for all Idle and Drive conditions are considered acceptable.

The following table summarizes the results of the Driveability Evaluation by various Management and Department Personnel for the Dual-Fuel development vehicle.

	COLD	WARM	HOT	PARTIAL COOLDOWN	AVERAGE RATING
START	7.3/7.9		8.6/8.6	8.5/8.3	8.1/8.3
IDLE	6.6/6.6	6.4/6.4	6.4/6.4	6.8/6.5	6.6/6.5
DRIVE	6.6/6.5	6.3/6.1	6.4/5.9	6.8/6.4	6.5/6.2

Gasoline Operation/Propane Operation

6. EMISSIONS AND FUEL CONSUMPTION EVALUATION

Emissions and Fuel Consumption comparisons were carried out using the Constant Volume Sampling tests.

Each test number represents a group of three consecutive test runs with the following variation in parameters:

- Test No. 1 identifies baseline data of the '86 production gasoline, fuel and induction system running on gasoline and an inertia weight of 2750 lbs.

- Test No. 2 incorporates the Dual-Fuel air induction system. The test fuel is gasoline and the inertia weight remains at 2750 lbs. This comparison identifies the effect of the Dual-Fuel air induction system on emissions and fuel consumption.

- Test No. 3 increases the inertia test weight to 3000 lbs. to account for the added weight of the Dual-Fuel System (fuel, fuel tank, carburetion, electronics, etc.). Once again the test fuel is gasoline with the inertia weight remaining at 3000 lbs.

- Test No. 4 uses propane as the test fuel, an inertia weight of 3000 lbs. and directly compares the Dual-Fuel induction system emissions and fuel economy to that of gasoline (Test No. 3). In this test while in the propane mode of operation, various features, earlier outlined, are either enabled or disabled.

- Test No. 5 demonstrates the optimum capabilities of the Dual-Fuel System. In this test the "cold transient phase" of the program is run in the propane mode of operation, while phase two and three are completed in the gasoline mode of operation.

6.1 Vehicle Emissions

The emissions test results are illustrated in Figure 12. Canadian 1986 passenger car emissions requirements are: HC - 2.0 gm/mile, CO - 25 gm/mile, and NOX - 3.1 gm/mile. All packages tested were significantly under these requirements.

The emissions results of Tests 1, 2 and 3 are all very similar. The addition of the dual-fuel inlet air system (Test #2) had only a minor effect on emissions. CO was increased marginally from 2.7 to 3.0 gm/mile. Increasing the inertia weight from 2750 lbs to 3000 lbs, to account for the extra weight of the propane fuel system, resulted in small increases in CO and NOX emissions.

Operating on propane increased HC and NOX emissions,in Test #4. The increased HC emissions may be the result of increased cyclic variations during lean operation, while increased NOX is a typical characteristic of propane. CO emissions are reduced because of lean part throttle operation and the lack of cold start enrichment with propane. CO_2 emissions are also reduced and are typical of propane operation.

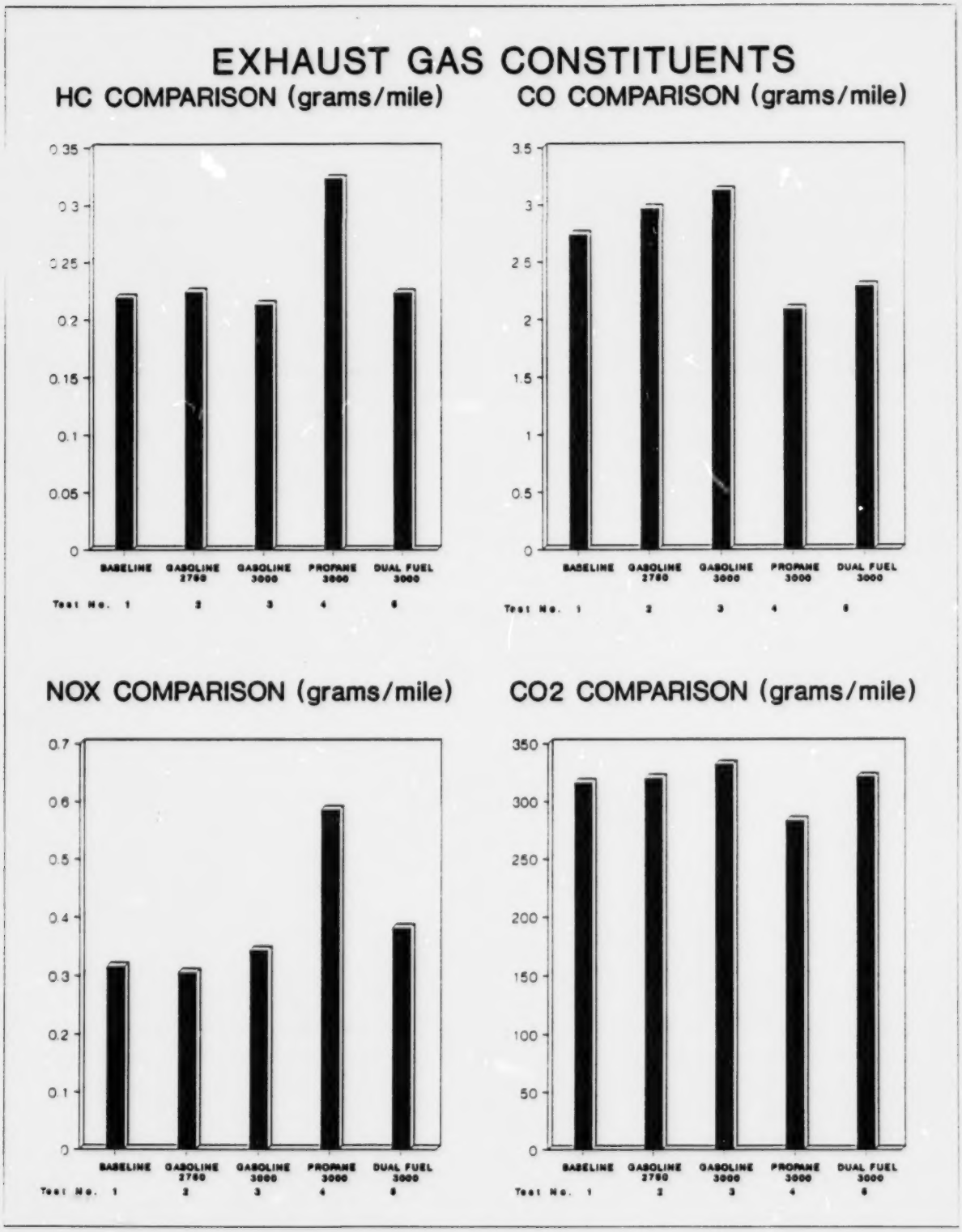

Figure 12 Emissions Comparison.

Test #5, with propane used for Bag 1 and gasoline used for Bags 2 & 3, resulted in reductions of HC and NOX emissions as compared to propane only operation while CO emissions were reduced from gasoline only operation. CO emissons were significantly reduced in Bag 1 as compared to gasoline because of the lack of cold enrichment. Bag 2 and 3 Test #5 results were similar to Test #3 Bag 2 and 3 results because the gasoline fuel calibration adaptive memory had not changed.

6.2 Vehicle Fuel Consumption

The addition of the dual-fuel inlet system (Test #2) increased fuel consumption by 3.72% and increasing the inertia weight to 3000 lbs (Test #3) increased fuel consumption by another 3.94%, resulting in a total increase in fuel consumption of 7.8% as compared to the baseline.

On a volumetric basis, operation on propane (Test #4) increased fuel consumption by 31.4% as compared to Test #3. However on an energy equivalent basis, energy efficiency was improved by 1.4%.

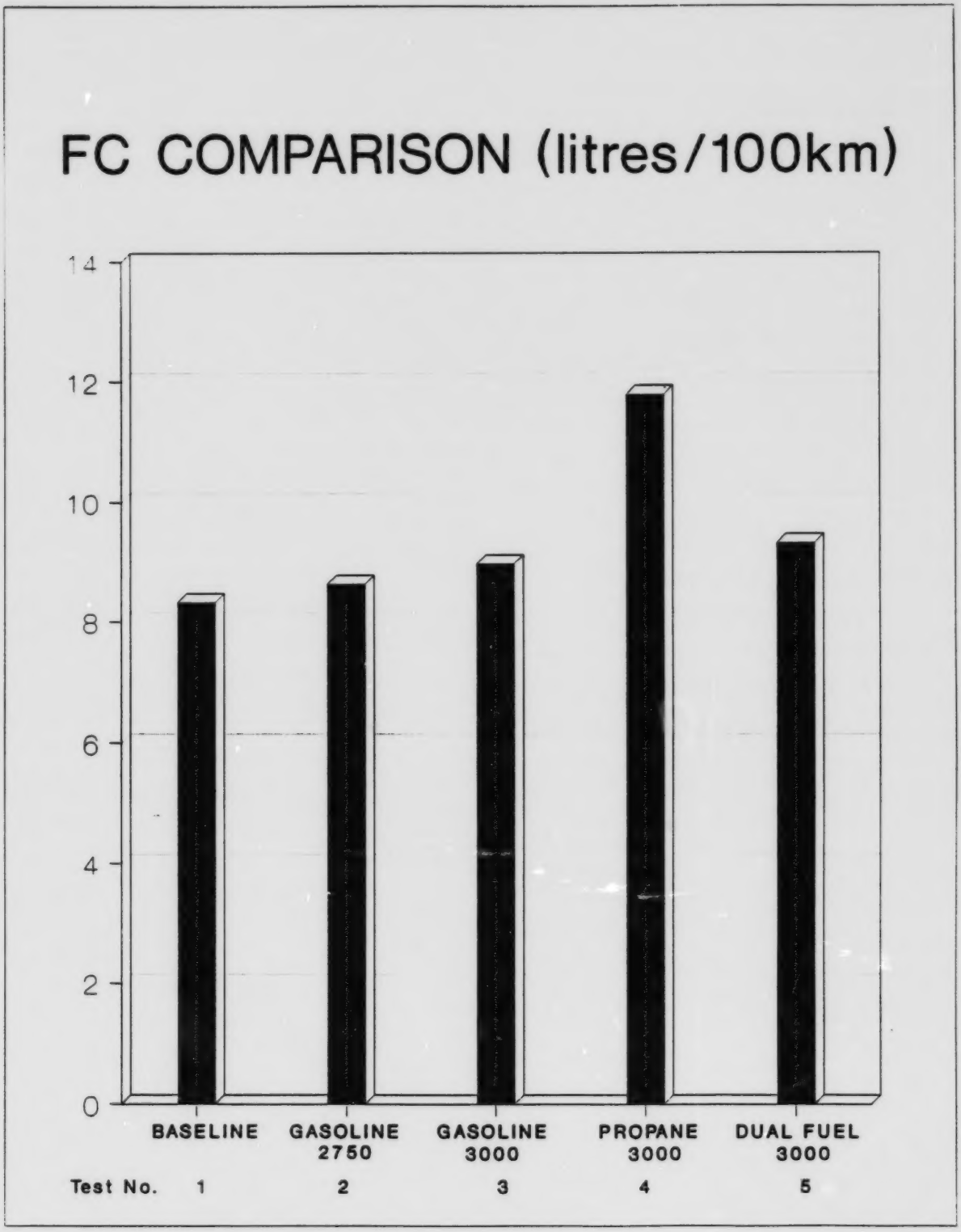

Figure 13 Fuel Economy Comparison.

7. CONCLUSIONS

(1) All emissions results otained from CVS testing were below Canadian requirements. Operation on proane reduced both CO and CO_2 emissions.

(2) The dual-fuel air induction system and the added weight increased fuel consumption by 7.8%. Operation on propane improved energy efficiency by 1.4% as compared to gasoline.

(3) Devices were developed to switch vehicle components for optimized operation on both fuels and for smooth fuel mode changes.

SECTION II

OPTIMIZATION OF COMPRESSION RATIO FOR A 2.5 L PROPANE-FUELED ENGINE

BY
CHRYSLER CANADA LTD.

JULY, 1988

ABSTRACT

An experimental study was performed to evaluate combustion chamber design and compression ratio in a propane-fueled 2.5-L four cylinder passenger car engine. The effects of inlet air temperature, inlet air humidity and minimum octane Grade 1 propane were also investigated. Fuel economy improvements were evaluated on a chassis dynamometer using constant volume sampling procedures.

The optimum compression ratio and combustion chamber package was determined to be 11.1:1 compression ratio with a "Fast Burn" type combustion chamber. This optimum package resulted in a City/Highway fuel economy improvement of 8.2% / 7.6% as compared to the baseline package.

RÉSUMÉ

Une étude expérimentale a été réalisée dans le but d'évaluer la conception d'une chambre de combustion ainsi que le taux de compression dans un moteur de 2,5 L à quatre cylindres de voiture propulsée au propane. Les effets de la température et du taux d'humidité de l'air d'arrivée, ainsi que le taux minimum d'octane contenu dans le propane de première qualité ont aussi fait l'objet de l'étude. La possibilité d'améliorer les économies de carburant a été évaluée à partir d'un dynamomètre de chassis selon les méthodes d'échantillonnage du volume constant.

Le taux de compression optimale été établi à 11.1 : 1 tandis que la chambre à combustion optimale était de type à combustion rapide. Cet ensemble permet un rapport de rendement amélioré ville et route de 8,2 % et de 7,6 % respectivement comparativement aux performances habituelles.

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FIGURE 5. 10.6:1 CR, Fast Burn Cylinder Head, KLSA and MBT.

FIGURE 6. 11.1:1 CR, Fast Burn Cylinder Head, KLSA and MBT.

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FIGURE 8. Effect of Intake Air Temperature on KLSA.

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FIGURE 10. Effect of Minimum Octane Grade 1 Propane on KLSA.

FIGURE 11. 11.1:1 CR, Fast Burn Cylinder Head, Governor S/A.

OPTIMIZATION OF COMPRESSION RATIO FOR A 2.5 L PROPANE-FUELED ENGINE

1. INTRODUCTION

The purpose of this study is to evaluate increased compression ratios and combustion chamber designs to increase the efficiency of a propane fueled 2.5 L engine.

Automotive propane engines are, in most cases, adaptations of gasoline engines and use standard compression ratios. Because of propane's higher octane rating, compared to gasoline, the potential for increasing engine efficiency through the use of higher compression ratios exists.

In recent years the introduction of Fast Burn combustion chambers in automotive engines has allowed higher compression ratios to be used without increasing engine octane requirements. The effect of these new chamber designs in propane-fueled engines was not known. Fast Burn type combustion chamber designs were evaluated in this study and compared to a "Bathtub" (Non-Fast Burn) type chamber.

As compression ratio increases, KLSA (Knock Limited Spark Advance) approaches MBT (Minimum Timing for Best Torque) and it becomes increasingly important to evaluate conditions, outside of the dynamometer test conditions, which may affect KLSA. Thus, the effect of inlet air temperature, inlet air humidity and minimum specification Grade 1 propane on KLSA were evaluated.

To evaluate the fuel economy benefits of increased compression ratio, baseline and optimum compression ratio engines were tested in a vehicle on a chassis dynamometer using constant volume sampling procedures.

2. TEST EQUIPMENT

2.1 Engine and Fuel System.

The base engine was a 1986 2.5 L four cylinder with a bore and stroke of 87.5 mm X 104 mm and a compression ratio of 9.0:1. The propane fuel system consisted of an Impco VFF 30 fuelock, a Model 'E' vaporizer with lean mixture control and a CA 100 mixer calibrated for the 2.5 L engine by Chrysler.

2.2 Test Vehicle.

The vehicle was a 1986 Plymouth Caravelle equipped with a three-speed automatic transaxle with a 3.02 overall top gear ratio. Propane fuel tanks and fuel system were installed on the vehicle.

2.3 Dynamometers.

275 horsepower eddy current engine dynamometers were used for engine testing. Vehicle tests were performed on a Clayton CT-150 chassis dynamometer using Beckman exhaust analyzers.

3. TEST PROCEDURES

3.1 Spark Loops.

Wide open throttle and part throttle spark loops were performed to determine KLSA and MBT. Inlet air temperature and engine coolant temperature were regulated between 35 ^{o}C - 40 ^{o}C and 80 ^{o}C - 90 ^{o}C respectively. Other engine test parameters were monitored and all engine torque and horsepower readings were corrected using SAE J1349.

3.2 Knock Limit.

At higher engine speeds audible knock is not easily determined, therefore in-cylinder pressure transducers were used to reliably determine the onset of combustion knock. Smooth pressure traces indicate normal combustion while broken up and spiked traces indicate knock.

4. COMBUSTION CHAMBER AND COMPRESSION RATIO TESTING

4.1 Combustion Chamber Design.

Three combustion chamber designs were used to determine the effect of chamber design on KLSA. The three combustion chambers tested were Bathtub, Fast Burn and Tapered Shroud Fast Burn. Fast Burn and Tapered Shroud Fast Burn cylinder heads were introduced by Chrysler for 1986 Model Year four cylinder engines to allow increased compression ratios to be used in these gasoline fueled engines. These Fast Burn chambers impart a swirling type motion to the air-fuel mixture as it enters the cylinder. The swirling of the mixture increases the rate of combustion, thus lowering its tendency to knock.

A comparison of the Bathtub and Fast Burn cylinder heads is shown in Figure 1. For the Fast Burn head, combustion chamber and intake port design changes were made to 'shroud' the intake valve and to create a 'directed' intake port.The Tapered Shroud Fast Burn is the same as the Fast Burn chamber except the intake shroud area is machined back at a 7 deg. angle to the valve guide.

FIGURE 1
COMPARISON OF FAST BURN AND BATHTUB HEAD DESIGNS

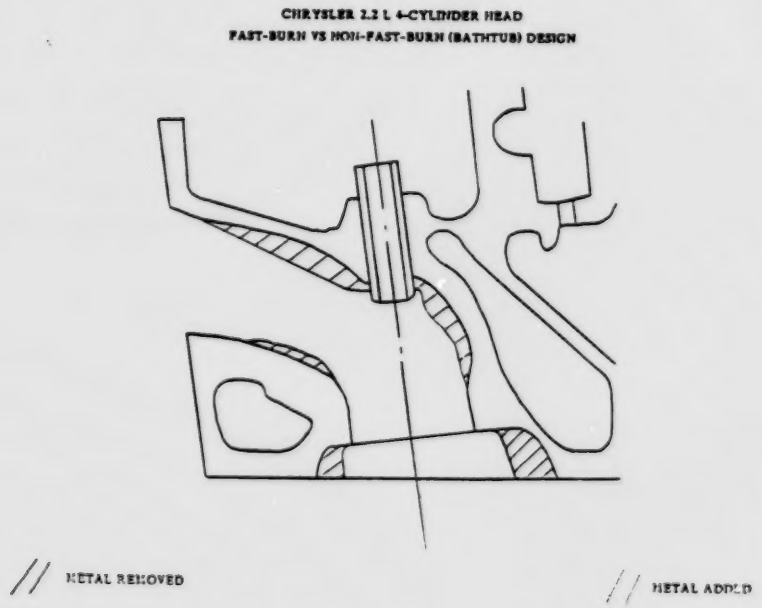
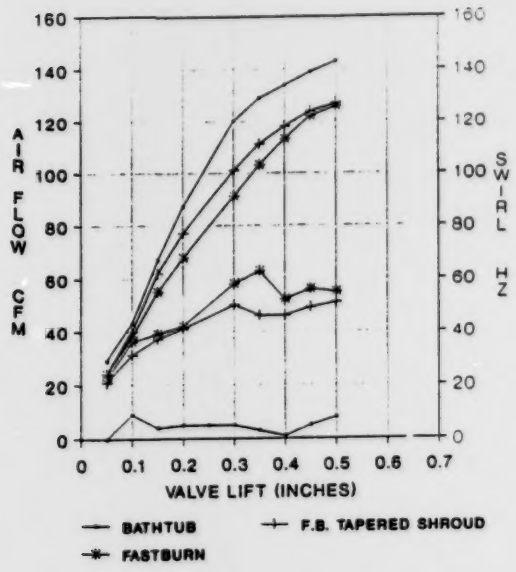


FIGURE 2
CYLINDER HEAD SWIRL AND FLOW COMPARISON



A comparison of the swirl rates and air flow for these three cylinder head configurations verses valve lift is shown in Figure 2. The Bathtub chamber results in minimal swirl and the highest air flow. The Tapered Shroud Fast Burn chamber was developed for use on the 2.2 L Turbo and 2.5 L naturally aspirated engines and has increased air flow capacity and lower swirl rates as compared to the Fast Burn chamber which is used on 2.2 L naturally aspirated engines. For this study the combustion chamber volumes of all three heads were equalized and the heads were modified to accept in-cylinder pressure transducers.

Piston and deck height changes were used to alter compression ratios. Chrysler production design criteria such as piston to valve and piston to head clearances were maintained.

4.2 Test Results.

All three heads were baseline tested at 9.0:1 compression ratio and then compression ratio was increased to 10.6:1. The compression ratio was then increased or decreased in 0.5 compression ratio steps until the knock limited compression ratio was determined for each head.

At 9.0:1 compression ratio a wide margin existed between KLSA and MBT with all three cylinder heads. The margin between MBT and KLSA was 8.1 deg., 6.5 deg. and 17.9 deg. for the Bathtub, Tapered Shroud Fast Burn and Fast Burn heads respectively. Because of the Bathtub heads higher airflow capacity, it had the highest power of 92.0 cbhp @ 4800rpm and torque of 131.6 lb.ft. @ 2800rpm. The Tapered Shroud Fast Burn head was down 3.6% power and 5.8% torque, while the Fast Burn head was down 5.9% power and 4.5% torque as compared to the Bathtub head. At 9.0:1 the Bathtub head was superior to the Tapered Shroud Fast Burn head, with increased power, torque, and MBT to KLSA margin.

Figures 3, 4 and 5 show MBT and KLSA at 10.6:1 compression ratio for the Bath Tub, Tapered Shroud Fast Burn and Fast Burn heads respectively. Both the Bathtub and the Tapered Shroud Fast Burn head MBT curves are knock limited while the Fast Burn head is not. The Bath Tub and Tapered Shroud Fast Burn heads were knock limited by 4.2 deg. and 1.7 deg. respectively while the Fast Burn head had an MBT to KLSA margin of 2.7 deg.. The Bathtub head resulted in the highest power of 99.9 cbhp @ 5200rpm followed by Tapered Shroud Fast Burn at 93.2 cbhp @ 4800rpm and Fast Burn at 92.7 cbhp @ 4800rpm. However the Fast Burn head resulted in the highest torque of the three heads at 132.1 lb.ft. @ 2800rpm. Comparing the MBT curves of the three heads at 10.6:1 compression ratio indicates that increasing swirl rates reduce MBT spark timing.

FIGURE 3
10.6:1 COMPRESSION RATIO
BATHTUB CYLINDER HEAD

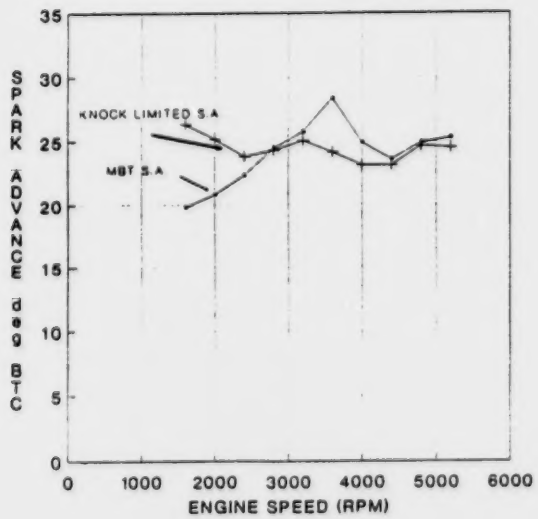


FIGURE 4
10.6:1 COMPRESSION RATIO
TAPERED SHROUD FASTBURN CYLINDER HEAD

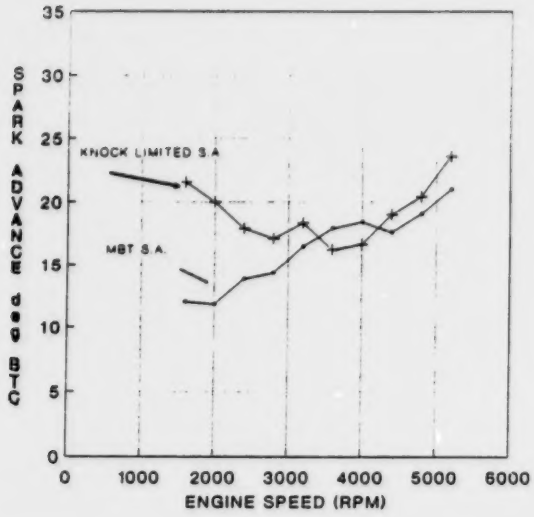
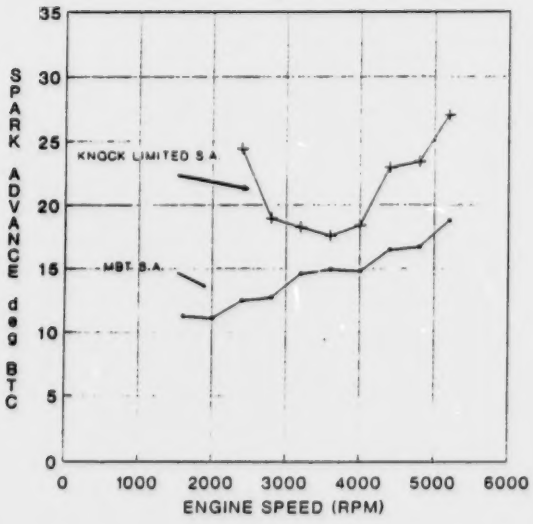


FIGURE 5
10.6:1 COMPRESSION RATIO
FAST BURN CYLINDER HEAD



The compression ratio was reduced to 10.1:1 for the Bathtub and Tapered Shroud Fast Burn heads. The Tapered Shroud Fast Burn head was not knock limited at 10.1:1 compression ratio and had a MBT to KLSA margin of 6.3 deg.. The Bathtub head was also not knock limited at 10.1:1 compression ratio, but at 3200 and 3600rpm the margin between MBT and KLSA was 0 deg., i.e. MBT and KLSA occurred at the same spark advance.

Compression ratio was increased to 11.1:1 for the Tapered Shroud Fast Burn and Fast Burn heads. The Tapered Shroud Fast Burn head was knock limited in the 4000 to 4800rpm range. The Fast Burn head was not knock limited at 11.1:1, but at 3600rpm the MBT to KLSA margin is 0 deg., as shown in Figure 6. As compared to 10.6:1 compression ratio the power and torque with the Fast Burn head was increased 1.7% and 0.8% respectively.

FIGURE 6
11.1:1 COMPRESSION RATIO
FAST BURN CYLINDER HEAD

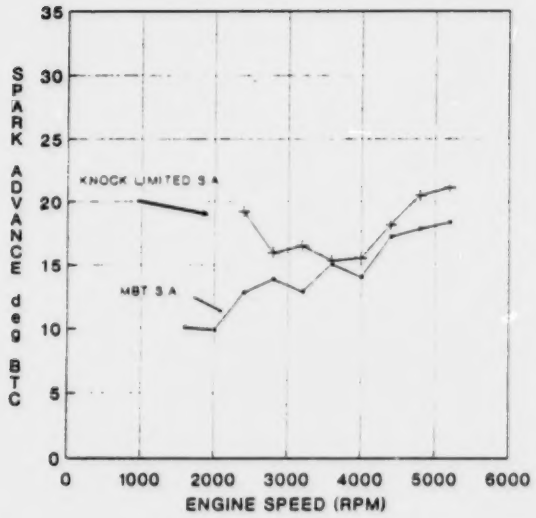
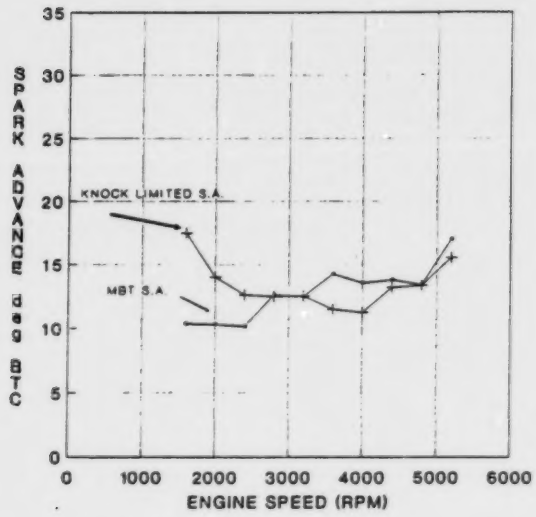


FIGURE 7
11.7:1 COMPRESSION RATIO
FAST BURN CYLINDER HEAD



The Fast Burn head was increased to 11.7:1 compression ratio and was knock limited in the 3200 to 4800rpm range, as shown in Figure 7. Horsepower and torque was increased by 1.4% and 1.3% respectively as compared to 11.1:1 compression ratio.

Therefore, these tests have shown that above 10.1:1 compression ratio the Bathtub head is knock limited, at 10.6:1 compression ratio the Tapered Shroud Fast Burn head is knock limited and above 11.1:1 compression ratio the Fast Burn head is knock limited.

A comparison of the baseline and 11.1:1 Fast Burn engine test results are shown in Table 2.

TABLE 2

COMPRESSION RATIO DEVELOPMENT RESULTS

	BASELINE	11.1:1 Fast Burn
COMPRESSION RATIO	9.0 : 1	11.1 : 1
COMBUSTION CHAMBER TYPE	TAPERED SHROUD FAST BURN	FAST BURN
TORQUE	124.0 LB.FT. @ 2800RPM	133.5 LB.FT. @ 2800RPM (+7.6 %)
HORSEPOWER	88.7 BHP @ 4800RPM	93.6 BHP @ 5200 RPM (+5.5 %)

5. INTAKE AIR TEMPERATURE AND HUMIDITY TESTING

As compression ratio is increased, and KLSA approaches MBT, it becomes increasingly important to determine the effect of operating conditions outside the dynamometer test conditions which may affect KLSA. Intake air temperature and humidity are two parameters which affect engine knock characteristics.

Wide Open Throttle spark loops were performed to determine the effect of intake air temperature and humidity on KLSA. The Tapered Shroud Fast Burn head with 10.6:1 compression ratio was used for this testing.

FIG. 8
EFFECT OF INTAKE AIR TEMPERATURE ON KLSA

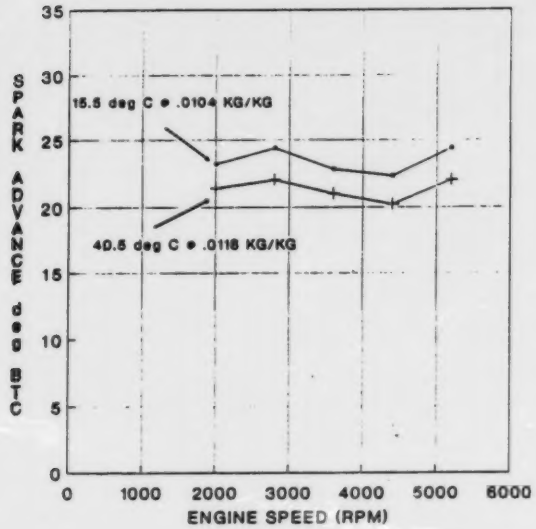
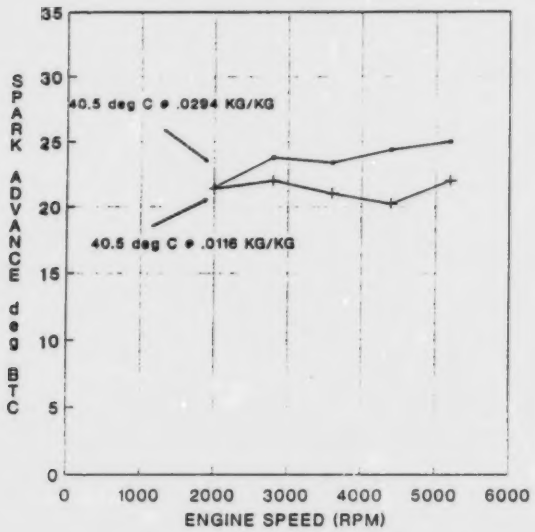


FIG. 9
EFFECT OF HUMIDITY ON KLSA



5.1 Test Results.

To determine the effect of temperature on KLSA, testing was performed at both 15.5 deg.C and 40.5 deg.C. Absolute humidity was held constant (within the capabilities of the equipment). At 15.5 deg.C, absolute humidity was 0.0104 kg/kg, 94% relative humidity and at 40.5 deg.C, absolute humidity was 0.0116 kg/kg, 25.5% relative humidity. As shown in Fig 8, the 25 deg.C increase in temperature reduced KLSA by an average of 2.0 deg. spark advance.

To evaluate the effect of humidity on KLSA, the inlet air temperature was held constant at 40.5 deg.C and absolute humidity was varied between 0.0116 kg /kg (25.5 % humidity) and 0.0294 kg / kg (60 % humidity). The average change in KLSA was 1.7 deg. with results shown in Figure 9.

6. MINIMUM OCTANE GRADE 1 PROPANE TESTING

Fuel quality is also an important factor in determining the knock characteristics of an engine. Combustion chamber and compression ratio testing was performed with commercially available Grade 1 propane. A specially blended propane fuel batch was aquired to determine the effect of a minimum octane blend which still meets the Grade 1 fuel specification. The fuel specification for this blend is shown in Table 1 and the calculated Motor Octane Number is 95, calculated using ASTM D2598.

TABLE 1

MINIMUM OCTANE PROPANE
FUEL SPECIFICATION

COMPONENT	LIQ. VOLUME %
PROPANE	92.5
PROPYLENE	5.0
ISOBUTANE	1.25
N-BUTANE	1.25

FIGURE 10
11.1:1 C.R. FAST BURN CYLINDER HEAD
KNOCK LIMITED SPARK ADVANCE

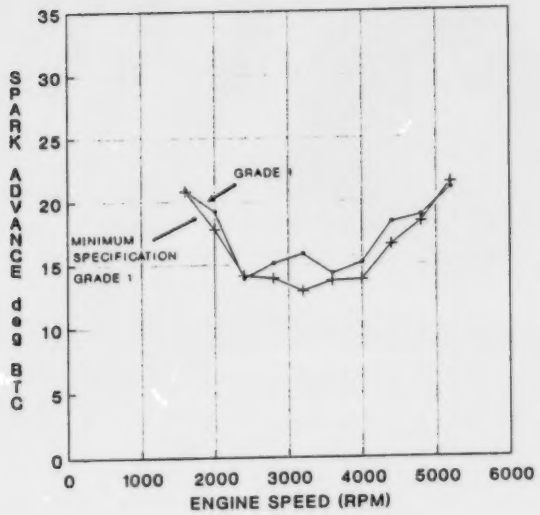


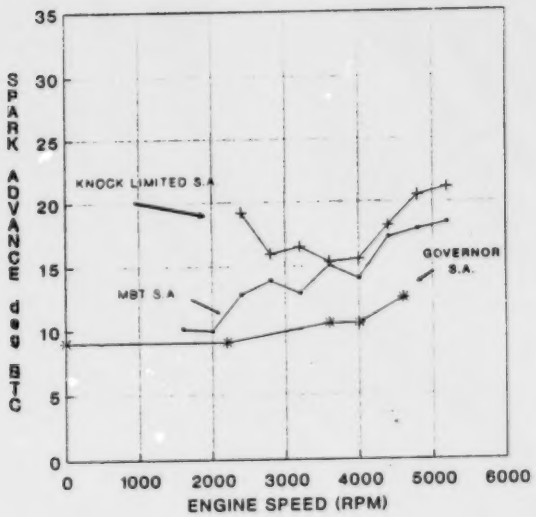
Figure 10 shows the results of this testing, which used 11.1:1 compression ratio and Fast Burn cylinder head. The minimum octane fuel lowered the KLSA from 0 deg. to 3 deg. depending on the rpm.

7. OPTIMUM COMPRESSION RATIO AND COMBUSTION CHAMBER

Engine dynamometer testing resulted in the Fast Burn cylinder head having the highest knock limited compression ratio, 11.1:1. This 11.1:1 / Fast Burn package was chosen to be the optimum compression ratio / combustion chamber package for this engine on propane.

To determine spark timing for the optimum package the effect of production compression ratio variations (plus or minus 0.5 ratio), inlet air temperature and humidity effects and the effect of fuel variations were all taken into consideration. The resultant governor spark advance is shown in Figure 11. Part throttle spark loops were also performed to determine the part throttle spark advance requirements.

FIGURE 11
11.1:1 COMPRESSION RATIO
FAST BURN CYLINDER HEAD



8. VEHICLE TESTING

8.1 CVS Testing

Three baseline and three optimum compression ratio CVS (Constant Volume Sampling) tests were performed with the test vehicle, a 1986 Plymouth Caravelle. Tests were performed on a Clayton CT-150 chassis dynamometer using Beckman emissions analyzers. The dynamometer settings were 2875 lbs. inertia test weight and 7.4 hp. road load power.

The CVS test fuel economy and emmissions results are shown in Table 3. The optimum compression ratio package improved City/Hwy fuel economy by 8.2 % and 7.6 % respectively. Emission results for both baseline and optimum tests were within the 1986 Canadian emission requirements for gasoline fueled passenger cars. As expected, NOx was increased at the higher compression ratio. CO emissions were reduced, and steady state road load tests indicate that the air-fuel ratio was slightly leaner at the higher compression ratio. HC emissions were increased, possibly as a result of reduced exhaust gas temperatures at 11.1:1 compression ratio.

TABLE 3

CVS Test Results

	BASELINE	OPTIMUM
Fuel Economy (mpig)		
City	21.81	23.60 (+8.2 %)
Hwy	28.88	31.09 (+7.6 %)
Exhaust Emissions (gpm)		
HC	.909	1.078
CO	15.20	9.43
NOx	2.246	2.684

8.2 Driveability Testing

The test vehicle was evaluated for driveability with baseline and optimum configurations. No deteriation in drivability was observed at 11.1:1 compression ratio and the increase in power was noted to improve vehicle performance.

9. ENGINE DURABILITY

Increasing the compression ratio of an engine may increase cylinder pressures beyond the design level of critical engine components. Engine durability testing and development would be required to ensure adequate engine durability is maintained.

10. CONCLUSIONS

1. For the 2.5 L engine the Fast Burn chamber design resulted in the highest knock limited compression ratio of 11.1:1.

2. Intake air temperature and humidity and fuel quality have a significant effect on the KLSA of a propane fueled engine.

3. The optimum compression ratio / combustion chamber package, of 11.1:1 and Fast Burn chamber, improved power and torque by 5.5 % and 7.6 % respctively and improved City / Hwy fuel economy by 8.2 % / 7.6 %.

SECTION III

THE DEVELOPMENT OF A COMPUTER-CONTROLLED PROPANE FUEL METERING SYSTEM

BY
CHRYSLER CANADA LTD.

OCTOBER, 1989

ABSTRACT

An experimental study was performed to develop a computer-controlled propane fuel metering system to optimize fuel economy and power. A low-pressure gaseous propane fuel metering system with open loop electronic control was developed.

Engine dynamometer testing was conducted to optimize the induction system, air-fuel ratio and spark advance for maximum power and minimum part throttle Brake Specific Fuel Consumption (BSFC). The fuel control system was based on a microcontroller design using a speed-density control strategy to modulate the reference pressure of the fuel regulator with a solenoid valve. Constant Volume Sampling emissions tests were performed to evaluate the fuel economy benefits of this optimised system over other existing propane systems.

This optimised system resulted in a 9% increase in maximum power and fuel consumption reductions in CVS city cycles of 8.8% and 10.9% as compared to conventional after-market and oxygen feedback carburetion packages, respectively.

RÉSUMÉ

Une étude expérimentale a été réalisée dans le but d'èffectuer la mise au point d'un système de dosage de propane par ordinateur pour maximiser le rendement sur les plan de l'économie et de la performance. On a mis au point un système de dosage de propane à faible pression muni d'un dispositif de contrôle électronique à circuit ouvert.

Des essais du moteur au dynamomètre ont permis de perfectionner le système à induction, le rapport d'air et carburant et l'allumage avancé pour obtenir une puissance maximale tout en étranglant les gaz au maximum. Le système de contrôle du carburant est modeler d'après un système de contrôle de la vitesse-densité qui sert à modifier la pression de référence du régulateur de carburant à l'aide d'une valve solenoidale. Des essais d'échantillonnage des émissions à volume constant ont été réalisés afin d'évaluer les avantages d'économies de carburants de ce système amélioré comparativement à d'autres systèmes existants utilisant le propane comme carburant.

Ce système a permis de réaliser une augmentation de 9 % de la puissance maximale et une réduction de carburant de 8,8 % et de 10,9 % en situation d'essais d'échantillonage à volume constant sur cycle de ville comparativement aux ensembles de conversion disponibles sur le marché et aux dispositifs de carburation de réaction à l'oxygène.

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1. INTRODUCTION

The purpose of this program is to develop a computer controlled fuel metering system to optimize fuel economy and power for Chrysler's 5.2 L propane engine thereby enhancing the efficiency in the utilization of propane as an automotive fuel.

Propane is a highly tolerant fuel for spark ignition engines because of its ability to sustain engine operation over a wide range of air-fuel ratios. Most aftermarket automotive propane conversions existing today use fuel system components that are manufactured for installation on a wide variety of engine configurations, and the fuel metering system is rarely calibrated correctly to meet the requirements of a specific engine. The engine performance and fuel economy are therefore greatly compromised resulting in inefficient utilization of the fuel. The development work presented in this report is aimed at addressing this problem using modern micro-electronic control technology.

The scope of the program encompassed optimization of the engine, development of the prototype fuel metering control system and demonstration of the fuel economy benefits. Initially, optimum air-fuel ratio and spark advance were determined on the engine dynamometer for maximum power at wide open throttle and minimum BSFC (Brake Specific Fuel Consumption) at part throttle. The engine air induction system was also redesigned to improve the intake air flow for maximum power. An open loop microcomputer based propane fuel metering system was then developed to accomplish optimum fuel metering control. Finally, CVS (Constant Volume Sampling) fuel economy comparison tests were performed on a test vehicle to demonstrate the fuel economy benefits of the prototype fuel metering system.

2. BACKGROUND

An investigation was conducted to identify the best method of improving fuel metering in the early stage of the program. A thorough assessment of the pros and cons of potential propane fuel metering technology has been treated in an interim report prepared for the Ontario Ministry of Energy; a copy of which can be found in Appendix 1. Three main types of fuel metering systems have been identified in the report, namely, liquid injection, high pressure gaseous and low pressure gaseous systems. All these systems can benefit from the increased precision and flexibilty of using electronic control. A comparison of the advantages and disadvantages of the systems are summmarized in Table 1. Based on the conclusion of that report, a low pressure gas-air mixer type of carburetion system with open loop computer control was selected as the most suitable system for this development work.

TYPE	ADVANTAGES	DISADVANTAGES
Low Pressure Gaseous System	. Reliable and simple . Good low temperature performance	. Lack of precise air-fuel ratio control
High Pressure Gaseous System	. Compact underhood packaging	. Poor cold temperature operation capability
Liquid Injection	. Increased power	. High cost . Low temperature icing . Two phase flow at high temperature
Electronic Control System with Oxygen Feedback	. Allows reduction catalyst usage	. Compromises fuel economy and power
Electronic Open Loop Control System	. Ability to optimize fuel economy and power . Cost effective	. Not optimum for reduction catalyst usage

Table 1. Summary of Main Advantages and Disadvantages of Potential Propane Fuel Metering Systems.

3. TEST EQUIPMENT INSTRUMENTATION AND FACILITES

3.1. Engine

The engine used for dynamometer testing was a Chrysler's 1988 5.2 Litre V8 Engine with fast burn combustion chamber design and 9.0:1 compression ratio. The propane fuel system was based on components manufactured by Impco Carburetion Inc. Impco's model E vaporizer-regulator and model CA225 air-gas mixer were used as base components for testing and development.

3.2. Engine Dynamometer Test Facilities and Instrumentation

Engine testing was performed on a 275 horsepower Eaton eddy current engine dynamometer (model No. 1014-1RW16) located at Chrysler Canada Ltd.'s Windsor facility.

A Digalog Cellmate 1 controller was used to conduct engine testing and data acquisition. Thermocouples and pressure transducers were used to monitor engine operating parameters and ambient conditions. Combustion pressure of the engine was monitored with a Kistler pressure transducer tapped into individual combustion chambers of the cylinder head. The pressure signal was displayed on an oscilloscope for visual detection of possible engine detonation and misfiring. A digital timing meter with analog output was used to monitor ignition timing advance. A "Dial Box" in conjunction with a special SMEC (Single Module Engine Controller) were used to change spark advance manually. A timer circuit for generating an adjustable frequency variable pulse width signal was built. It was used with the fuel metering solenoid for manual control of the air-fuel ratio on the test engine.

A Horiba exhaust gas emissions analysis bench with magnetopneumatic oxygen analyzer (5/10% range), flame ionization hydrocarbon analyzer (1K ppm range), and non-dispersive infrared carbon monoxide (5/10% range) and carbon dioxide (8/16% range) analyzers was used to monitor the air-fuel mixture ratio of the engine. An NGK wide range oxygen sensor was also used to correlate the air-fuel ratio test data.

A 460 SCFM Meriam laminar flow airflow meter (model No. 50MC2-6F) fitted with a Viatran pressure transducer was used to measure the engine intake air flow rate. A surge tank was installed in the air intake system to settle the intake air flow after the the airflow meter.

Two Sidetrack gaseous flowmeters of hot wire anemometer type manufactured by Sierra Instruments Inc. were used to measure gaseous propane fuel flow rate at different ranges. Liquid propane fuel was vaporized through a vaporizer-regulator housed inside a vessel. By filling the vessel with compressed air to provide a reference pressure for the

regulator, vaporized propane was maintained at 20 psig of pressure. The vaporized propane was then branched off to a pair of Balston type 33-S6 coalescing filters before entering the flowmeters. The two flowmeters were connected in parallel and operated exclusive of each other with the smaller one used to measure flow rates up to 0.5 lb/min. and the larger one up to 2.0 lbs/min.

3.3. Test Vehicles and Instrumentation

Two identical 1988 model Dodge B250 vans were used for fuel metering system calibration development and CVS fuel economy tests. The vehicles had 5.2 L engines coupled to A727 three speed automatic transmissions with 2.94:1 axle ratio and were equipped with the same accessories. The engine electronic system of the vehicles were managed by a SMEC.

A SMEC controlled Throttle Body Injection system was used when the vehicle was initially tested on gasoline. Indolene was used as the standard test fuel for gasoline, and CGSB Grade 1 for propane.

An NGK wide range oxygen sensor (with 0-5VDC output) was inserted in the vehicle exhaust system to monitor the overall mixture air-fuel ratio. A Chrysler "Interrogation Box" was used to acquire engine sensor readings registered in the memory of the SMEC and convert them into analog signals. For detail analysis, these signals were recorded on board the test vehicle with an 8-channel Gould strip chart recorder which was powered by a DC to AC inverter.

3.4. Chassis Dynamometer Test Facilities

CVS fuel economy comparison testing was conducted at Chrysler's Emissions and Fuel Economy Certification Laboratory. Each chassis dynamometer test cell of the laboratory was equipped with CVS exhaust emission benches to sample engine and tailpipe emission constituents for computerized quantitative analysis. CVS test procedures similar to the specifications of CMVSS 1103 [Ref.1] were used for the testing.

4. ENGINE DYNAMOMETER TESTING

4.1. WOT Optimization

The best torque air-fuel ratios at the normal operating speeds of the engine were measured initially for use as a target. The air-gas metering valve of the standard carburetor was then redesigned through an iterative testing process in order to meet the requirements of the target air-fuel ratios. When the 1988 Chrysler's production propane package was compared with gasoline, the torque and horse power at WOT (Wide Open Throttle) were reduced by 3.5% and 10% respectively. In order to regain some of the

lost power output, the induction system was modified to remove some of the flow restrictions.

Engine power testing was performed according to the convention and practice of SAE J1349 standard [Ref.2]. Torque and power are broadly used in this report to represent values corrected for variations in intake air temperature and humidity content. The procedures used for these tests are outlined in section 4.1.1.

4.1.1. WOT Engine Testing Procedures

1) Power and Torque Rating

WOT power and torque curves were obtained at engine speeds ranging from 1200 to 4400 RPM at 400 RPM intervals. At each test point the air-fuel ratio was defined by the fuel metering system setting and the spark advance was adjusted to provide optimum torque. This procedure was used to compare output performance of various induction and carburetion system configurations.

2) WOT Optimum Air-fuel Ratio Mapping Procedure

The engine was tested at speeds ranging from 1200 RPM to 4400 RPM at 400 RPM increments at WOT. At each speed test point, the air-fuel ratio was varied from 13:1 to 17:1 at 1 ratio increments. Spark advance at each test setting was adjusted to obtain optimum torque. Air-fuel ratio for optimum torque output at each speed test point was determined from a graph of torque versus air-fuel ratio.

3) WOT MBT Spark Advance Mapping Procedure

At each speed and optimum air-fuel ratio setting, torque was observed while spark advance was varied between 20° and 40° BTC at 2° to 4° intervals. MBT (Minimum for Best Torque) spark advance was determined from a graph of torque versus spark advance.

4.1.2. WOT Engine Optimization Test Results

The best torque air-fuel ratio was found to range from 14.5:1 to 14.7:1 (see Figure 1 and Figure 2). The standard air-gas metering valve was tested to determine its deviation from the optimum air-fuel ratios. From Figure 1, it is apparent that the air-fuel mixture is too lean at low engine speeds and too rich at high speeds. By changing the dimensions of the metering valve profile, the fuel metering characteristic of the valve was altered. After a series of tests and modifications, a new metering valve with a profile as shown in Figure 2 was developed. The air-fuel ratio distribution of the resulting metering valve matched the optimum air-fuel closely as shown in Figure 3.

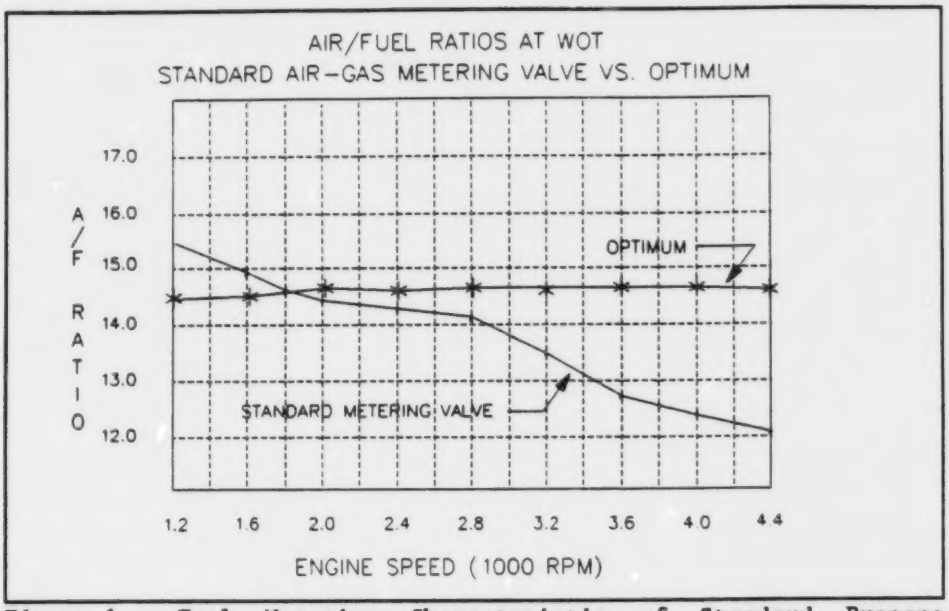

Figure 1. Fuel Metering Characteristic of Standard Propane Metering Valve vs. Optimum air/fuel ratio for Best Torque.

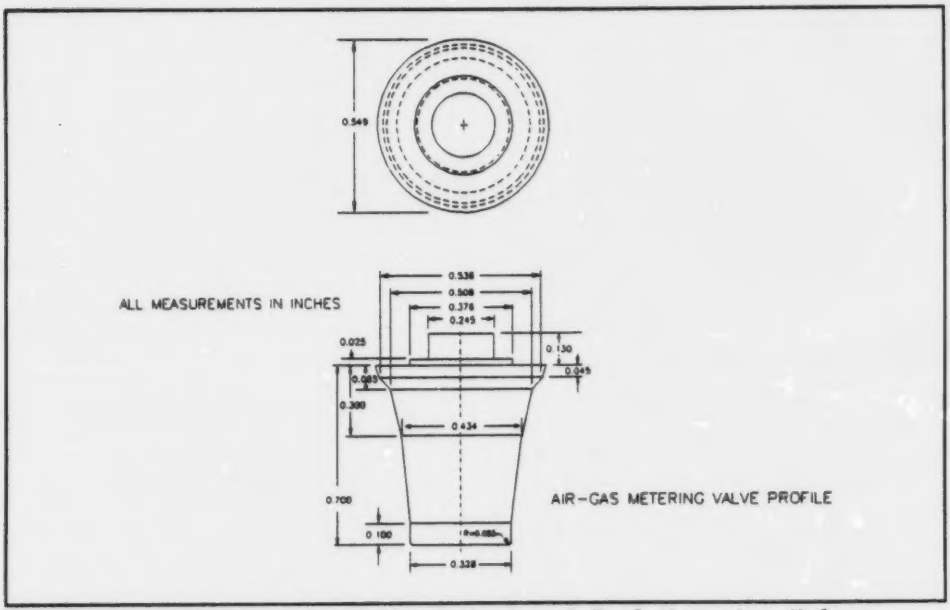

Figure 2. Dimensions of the Redesigned Fuel Metering Valve.

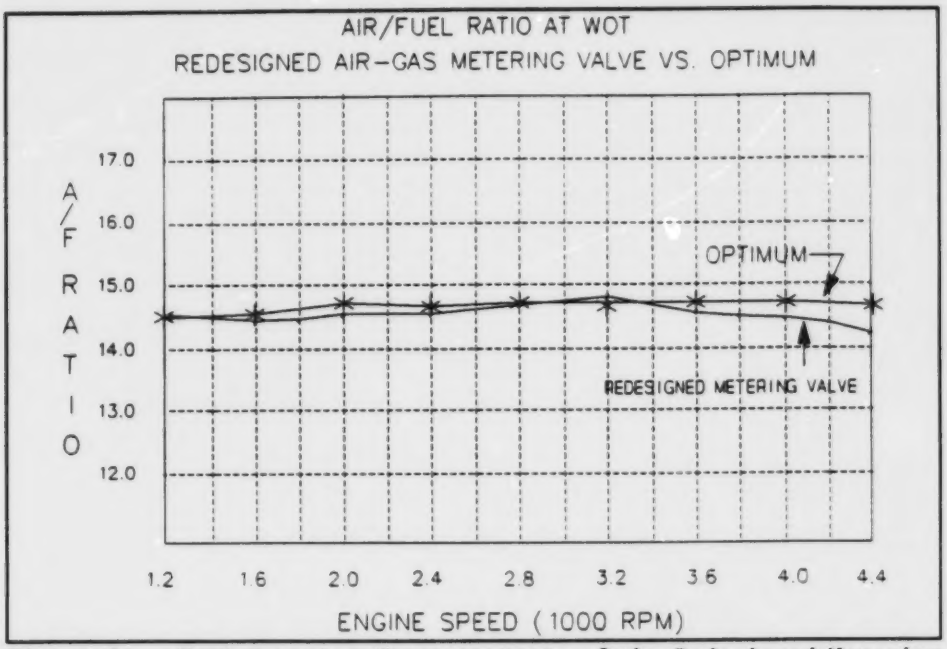

Figure 3. **Fuel Metering Characteristic of the Redesigned Metering Valve vs. Optimum Air/Fuel Ratio for Best Torque.**

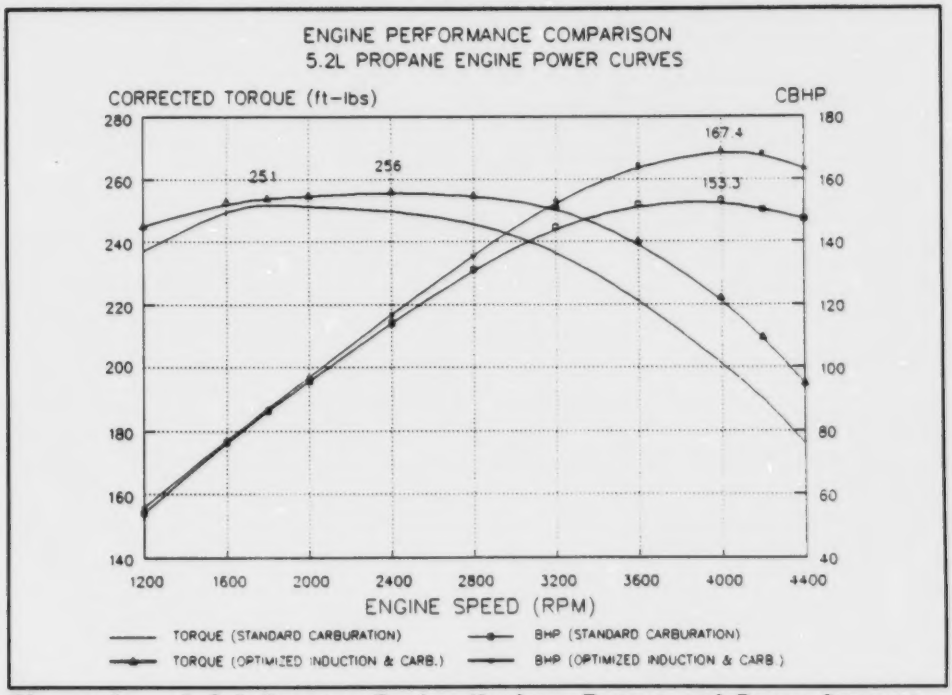

Figure 4. 5.2 L Propane Engine Maximum Torque and Power Outputs - Standard vs. Improved Induction and Fuel Metering Systems.

The engine induction system modifications included using a larger throttle body - 50mm bore diameters versus 38mm, reworking the intake manifold to match up with the enlarged throttle body, and using a dual snorkel air cleaner instead of the standard single snorkel unit. The induction system modifications and the redesigned mixer gas-air metering valve resulted in 9% improvement in maximum power output when compared to the standard propane carburetion package (see Figure 4).

4.2. Part Throttle Optimization

Engine maps of optimum air-fuel ratio for minimum BSFC and optimum spark advance at part throttle were determined in this part of the testing. Procedures for these tests are outlined in sections 4.2.1.

4.2.1. Part Throttle Engine Mapping and Optimization Test Procedures

1) Mapping of Air-fuel Ratio for Minimum BSFC

Two methods were used to measure the propane fuel consumption rate of the engine. The first method used the Sierra flow meters with factory calibrations, and the second method used the air flow rate measured with the Meriam air flow meter and the air-fuel ratio measured with the emission analyzers to calculate the fuel flow rate. Using the data obtained from each method to cross check against one another, the accuracy of the fuel flow rate measurements was assured. The mixture air-fuel ratio was varied with a fuel metering solenoid valve driven by a timer circuit.

In order to determine the optimum air-fuel ratio for minimum BSFC at a constant engine speed and load, the fuel flow rate was measured while the air-fuel ratio was varied between 15.7:1 to 22.5:1 at about 1 ratio intervals. Spark advance was adjusted to obtain minimum engine MAP (Manifold Absolute Pressure) reading at each test point. The air-fuel ratio corresponding to the minimum BSFC point represents the optimum for the given engine speed and torque. Engine operating parameters and pulse widths of the fuel metering solenoid driver signal required to achieve the air-fuel ratio settings were recorded. The test procedure was repeated for the same engine speed at various constant torque settings ranging from light throttle (corresponding to engine manifold vacuum of about 20" of Hg) to heavy throttle (up to 5" of Hg of vacuum). The same process was repeated for different engine speeds ranging from 1200 to 3600 RPM at 200 RPM intervals.

2) Mapping of Optimum Part Throttle Spark Advance

After the optimum air-fuel ratio for each speed and load point was obtained, the optimum spark advance was more precisely mapped. The engine was operated at

constant speed and torque with the air-fuel ratio adjusted to the optimum. Engine MAP was recorded while spark advance was varied between 30° and 50°BTC at about 4° intervals. Optimum spark advance corresponds to minimum MAP. To obtain an engine map of optimum spark advance, the procedure was repeated for the same speed and torque settings used in mapping optimum air-fuel ratios.

4.2.2. Part Throttle Optimization Test Results

Optimum air-fuel ratio for minimum BSFC for a given speed and torque setting was obtained from curves such as the ones shown in Figure 5. The surface map shown in Figure 6 represents a summary of the optimum air-fuel ratio obtained through this testing. The optimum air-fuel ratio ranged between 17.5:1 to 20.5:1. Signs of misfiring began to occur at air-fuel ratio of around 21:1. By examining the BSFC vs. air-fuel ratio curves, a reduction in BSFC of between 3% to 12% could be obtained by increasing the air-fuel ratio from stoichiometric (15.7:1 for Grade 1 propane) to optimum (typically around 20:1).

The surface map as shown in Figure 7 summarizes the test results of optimum spark advance at minimum BSFC air-fuel ratios. The optimum spark advance ranged from 32° to 44°BTC within the normal operating range of the engine.

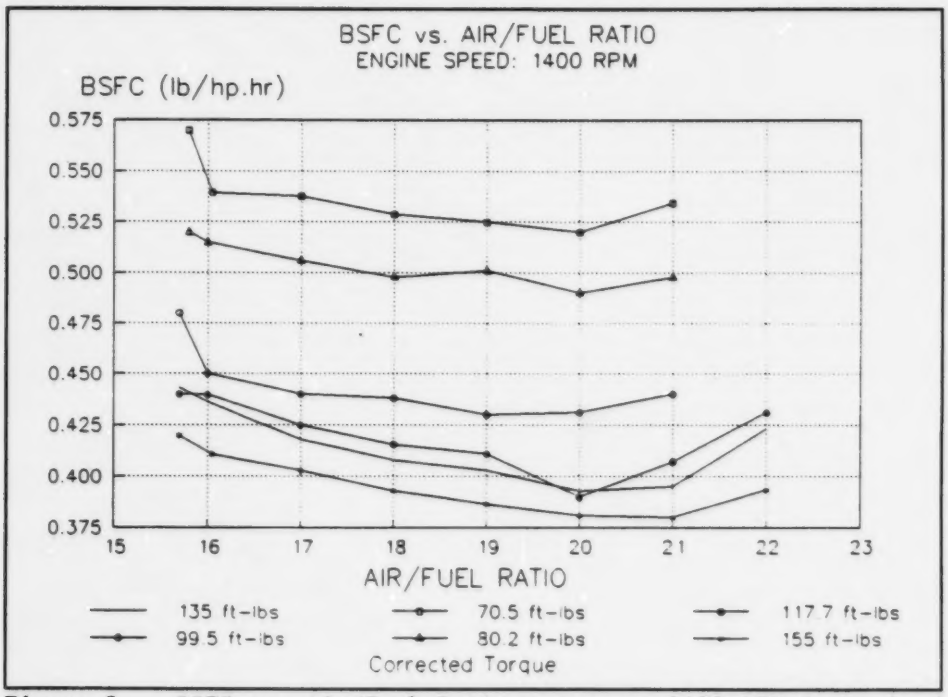

Figure 5. BSFC vs. Air/Fuel Ratio curves at 1400 RPM Summarized from Part Throttle Optimization Test Data.

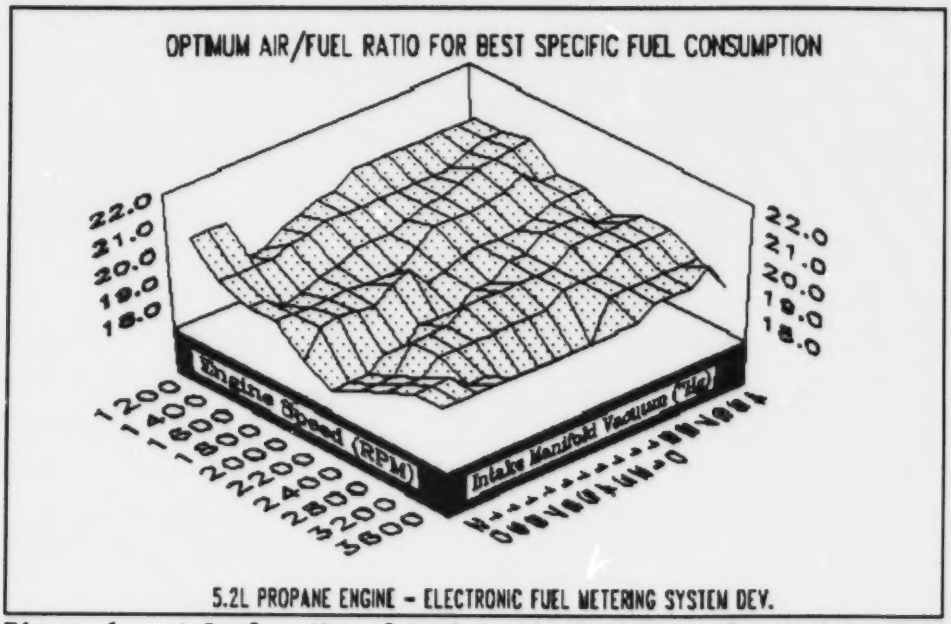

Figure 6. A Surface Map of Optimum Air/Fuel Ratio for Minimum BSFC Obtained from Part Throttle Optimization.

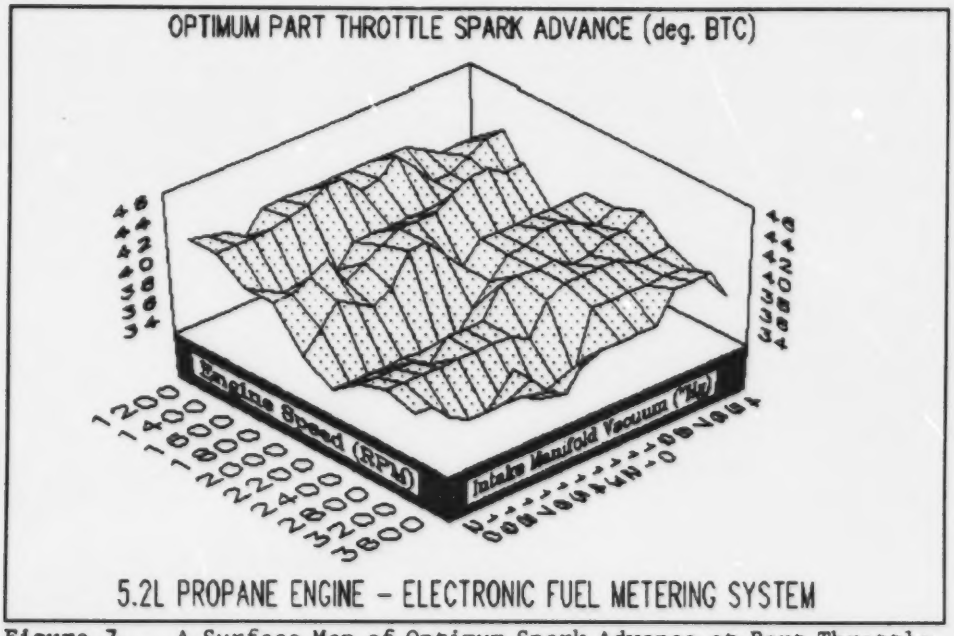

Figure 7. A Surface Map of Optimum Spark Advance at Part Throttle.

5. DEVELOPMENT OF THE PROPANE FUEL METERING SYSTEM

5.1. Overview of Fuel Metering System Design

The basic design concept of the open loop propane fuel metering system features the following:

- The electronic control system can be adapted readily to existing propane fuel metering equipment to reduce vehicle fuel consumption.
- The fuel metering calibration can be modified easily to meet the requirements of different engine configuration.
- The add-on electronic control can be overridden in case of system malfunction; and the engine can be operated in a limp-in mode by reverting to mechanical fuel metering operation.
- There is a provision for manual on-vehicle adjustment or calibration of air-fuel ratio via an external potentiometer.
- On rapid deceleration, the engine fuel consumption is further reduced by providing a very lean air-fuel ratio.

The fuel metering control system is evolved from a commercially available propane carburetion system. The basic components of the system include a gas-air mixer type of carburetor, a vaporizer-regulator and a micro-computer controlled vacuum solenoid valve sub-system for controlling fuel flow.

The air-fuel ratio for a given engine operating condition is governed by the fuel supply pressure, the flow area set by the gas metering valve opening in the mixer, and the mixer vacuum. The control system uses the concept of altering the fuel supply pressure in the regulator in order to achieve a wide range of fuel flow control. This is accomplished by modulating the reference pressure of the regulator with mixer vacuum through a pulsed solenoid valve.

The gas valve of the carburetor is optimized for Chrysler's 5.2 L propane engine to provide optimum air-fuel ratio for maximum power output at WOT. At part throttle, it delivers an intermediate air-fuel ratio of between 15:1 to 18:1 in a default situation when the computer control is overridden by venting the regulator reference pressure directly to balance line pressure. This will provide a fail-safe engine operating mode in an unlikely event of computer failure. During normal operations, when the computer is controlling the fuel metering solenoid valve, the steady state air-fuel ratio at part throttle is adjusted between 17.5:1 to 20.5:1, corresponding to the optimum for best fuel economy.

By properly calibrating the data used by the computer to determine the electrical command signal that drives the fuel metering solenoid valve, optimum air-fuel ratios for maximum power at WOT and best fuel economy at part throttle operations can be achieved.

5.2. Mechanical Sub-System Design

The primary mechanical components of the propane fuel metering system was derived from a conventional carburetor with a gas-air mixer and a vaporizer-regulator. The gas valve of the carburetor was replaced by one devised experimentally during the engine optimization stage. A fuel metering solenoid valve selected from readily available automotive exhaust emission control equipment was used for steady state air-fuel ratio control. Similar solenoid valves were used as optional auxiliary vent solenoid valves for transient control during acceleration and deceleration (see Figure 8).

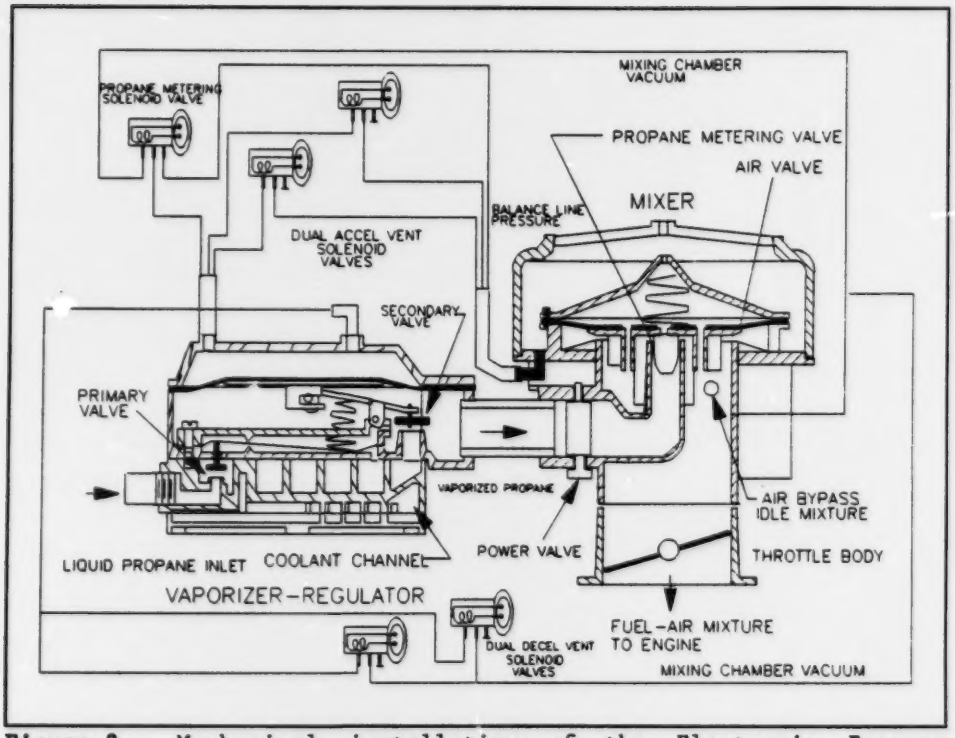

Figure 8. Mechanical installation of the Electronic Propane Metering System.

The spring loaded diaphragm valve in the secondary chamber of the vaporizer-regulator regulates the pressure of vaporized propane fuel entering the carburetor. The reference pressure above the diaphragm valve governs the pressure of the vaporized fuel by acting against the spring force which tends to close the valve. Unlike the conventional system which vents the reference pressure chamber above the diaphragm valve to balance line pressure (the pressure of the intake air downstream of the air cleaner), the computer controlled metering solenoid valve modulates the reference pressure by switching it intermittently between carburetor mixer vacuum and balance line pressure. As the solenoid duty cycle varies, the reference pressure responds proportionally between the two limiting pressure levels resulting in a wide range of change in fuel regulating pressure. For example, the mixer vacuum normally varies between 4 inches to 12 inches of water below atmospheric pressure depending on the engine operating condition. The balance line pressure is equal to or slightly below atmospheric pressure. An intermediate reference pressure of about 6.5 inches of water below atmospheric is sufficient to achieve a typical optimum air-fuel ratio of approximately 20:1. Thus, the system is capable of metering fuel flow over a very wide range.

Three solenoid valve configurations with varying degrees of complexity were evaluated during the development process with each found to show distinct transient response characteristics.

The first configuration evaluated used a single three-port two-way solenoid. The output port was connected to the reference pressure chamber of the regulator. One of the two input ports was connected to a vacuum port at the mixer and the other was connected to the balance line pressure tap at the carburetor. During on-vehicle driveability evaluation, the metering solenoid valve was able to maintain optimum air-fuel ratios at steady state engine operations. However, a driveability problem was encountered during acceleration when the throttle was opened rapidly. The engine was momentarily starved of fuel and exhibited surge and hesitation. As a result, a pair of "acceleration" solenoids were added to the system to solve this driveability problem. These two solenoids were operated synchronously by the computer to provide two extra flow paths to bypass the reference pressure to balance line pressure for a brief period of time when the rate of change in throttle position exceeds a programmable level. With the restriction of pressure signal transmitted through the metering solenoid valve removed during this transitional period, the response of the diaphragm valve to a sudden increase in fuel demand during acute accelerations was improved and the surge and hesitation problem was eliminated.

The second configuration is similar to the first configuration described above except for the addition of two "deceleration" vent solenoid valves (see Figure 8). These two solenoid valves were energized by the computer to vent mixer vacuum for a short period of time during rapid deceleration when the negative rate of throttle displacement exceeds a programmable level. This feature was added to prevent the air-fuel mixture

from becoming over rich during rapid deceleration as was observed during on-vehicle testing.

The third and final configuration applies the same concept with a slight variation. Instead of using a three port solenoid valve, it used a single two-port one-way high flow rate solenoid valve (rated at 50 litres/min. at 16 Hz) to switch in the mixer vacuum to modulate the reference pressure. A carefully sized orifice of 0.100 inch diameter was used to restrict a continuous flow from balance line pressure to the reference pressure chamber (see Figure 9). The mixer vacuum line and the balance line were connected together to a T-connector which led to the reference pressure chamber.

Through the on-vehicle evaluation and calibration process discussed in Section 5.4, the single two-port one-way solenoid configuration described above was found to be the most effective. It provided reduced fuel consumption and better driveability than the three and five solenoid configurations without the need for additional solenoid valves to manage transient response. Therefore this final configuration was adopted for use in the CVS fuel economy comparison tests.

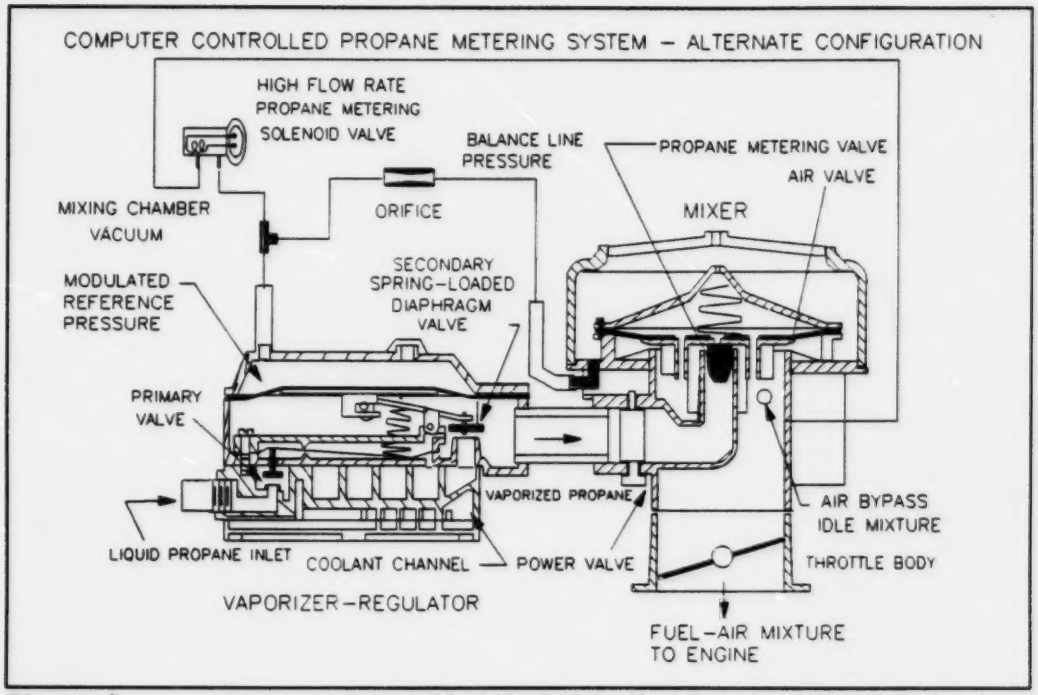

Figure 9. Computer Controlled Fuel Metering System - Final Mechanical Configuration.

5.3. Electronic Control Sub-System Design

The development vehicle had a factory installed electronic engine control system which included a SMEC and various engine sensors. In order to simplify the development of software and hardware for the fuel metering functions, a separate fuel metering controller module was used. The SMEC was retained for spark ignition timing control and propane start-assist solenoid valve control which was incidentally a standard feature for Chrysler's 1988 model propane vehicles. A special SMEC with removable EPROM (Erasable Programmable Read Only Memory) socket was used to facilitate spark timing calibration changes. A spark advance schedule as shown in Figure 10 was derived from engine dynamometer test data and programmed into the SMEC for optimum ignition timing control.

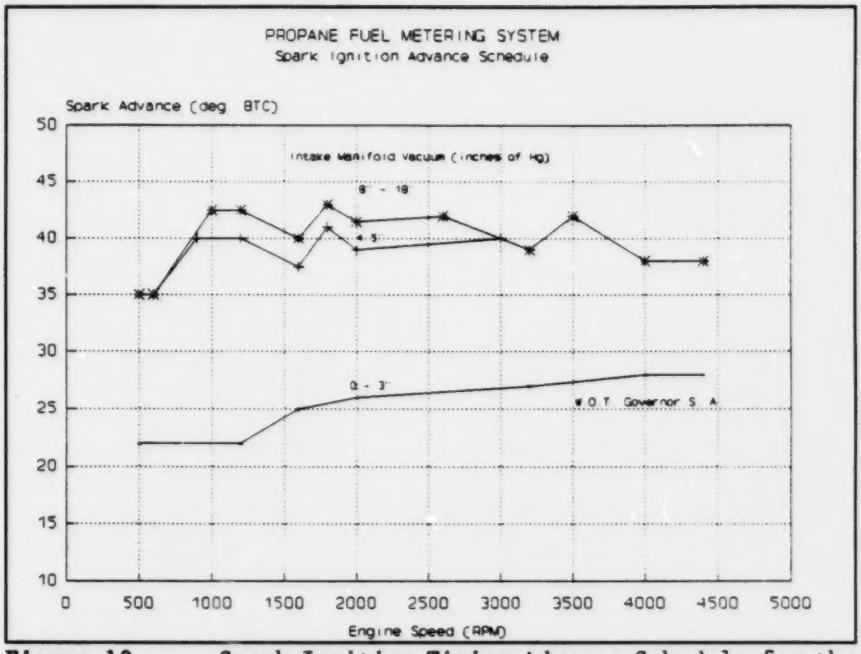

Figure 10. Spark Ignition Timing Advance Schedule for the Propane Fuel Metering System.

The fuel metering controller used a 10 Hz fixed frequency variable pulse width electrical signal to drive the reference pressure modulating fuel metering solenoid valve. It shared the same engine sensors as the SMEC except for the engine coolant temperature sensor. A separate coolant temperature sensor was used to allow the controller to actively select between two different temperature scales required to obtain accurate readings at a wide range of temperature. A schematic diagram for the Engine Control System is as shown in Figure 11.

An electronic circuit board using an Intel 8097 microcontroller was selected for developing the propane fuel controller. Two prototype modules were built. One was used for system development and the other for installation in the test vehicle for subsequent CVS tests. The software of the controller was developed on an IBM XT personal computer using Intel's ASM96 macro assembler. An SBE-96 emulator circuit board manufactured by Intel Corporation was used to debug the controller module throughout the course of the development. The controller module used on the test vehicle consists of three major components which are the microcontroller board, the power supply unit, and the sensor and driver interface board. The microcontroller board has two eight-kilobyte 2764 EPROM's for program codes and calibration data storage (see Figure 12). The allocation of the controller resources is as shown in Figure 13. Figure 14 depicts the memory map of the controller. The input-output interface board contains the buffer and signal conditioning circuits for the sensor input signals and the driver circuits for the five solenoid valves used in the system.

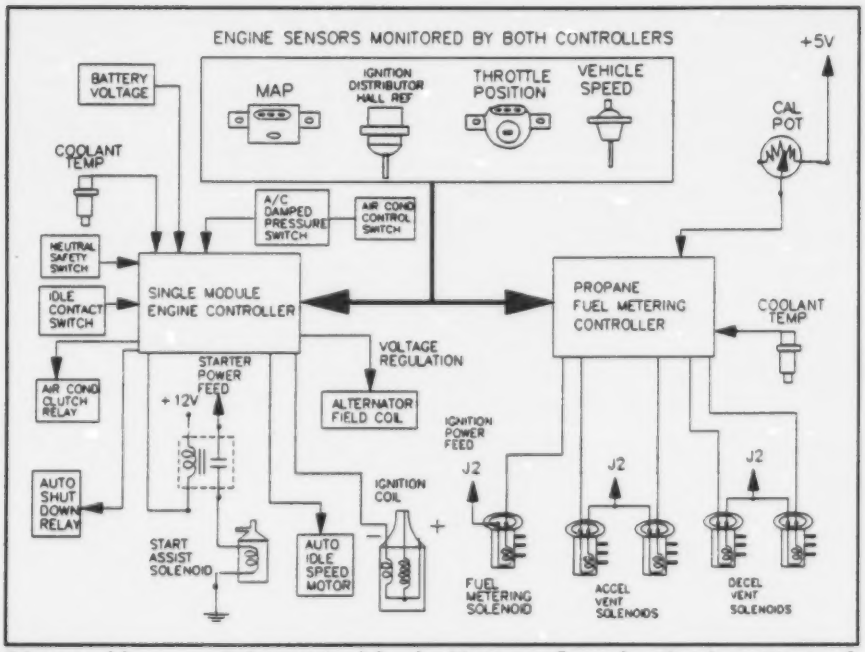

Figure 11. Schematic block diagram for the Engine Control System.

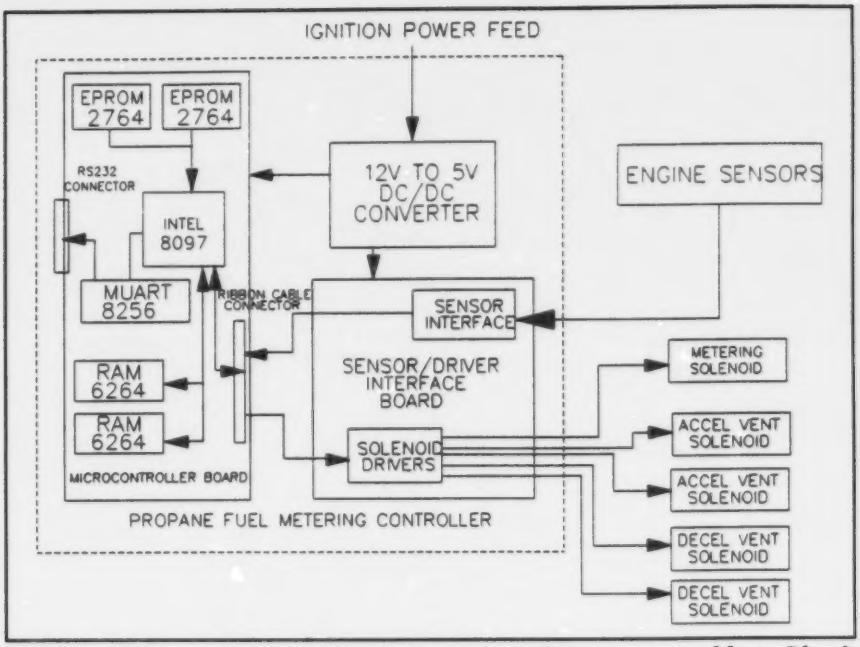

Figure 12. **Propane Fuel Metering Micro-controller Block Diagram.**

ASSIGNMENT OF 8097 RESOURCES

ANALOG CHANNELS

ACH0	MAP
ACH1	CAL POT
ACH2	NOT USED
ACH3	NOT USED
ACH4	COOLANT TEMP
ACH5	THROTTLE POT
ACH6	NOT USED
ACH7	NOT USED

HIGH SPEED INPUTS

HSI0	NOT USED
HSI1	VEHICLE SPEED
HSI2	DIST HALL EFFECT
HSI3	NOT USED

HIGH SPEED OUTPUTS

HSO0	NOT USED
HSO1	METERING SOL
HSO2	NOT USED
HSO3	NOT USED

I/O PORT 1

P1.0	COOLANT TEMP SCALE SWITCHING
P1.1	ACCEL VENT SOL
P1.2	ACCEL VENT SOL
P1.3	DECEL VENT SOL
P1.4	DECEL VENT SOL
P1.5	NOT USED
P1.6	NOT USED
P1.7	NOT USED
NMI	8256 INTERRUPT

Figure 13. **Allocation of Micro-controller Resources for Input/Output Interface.**

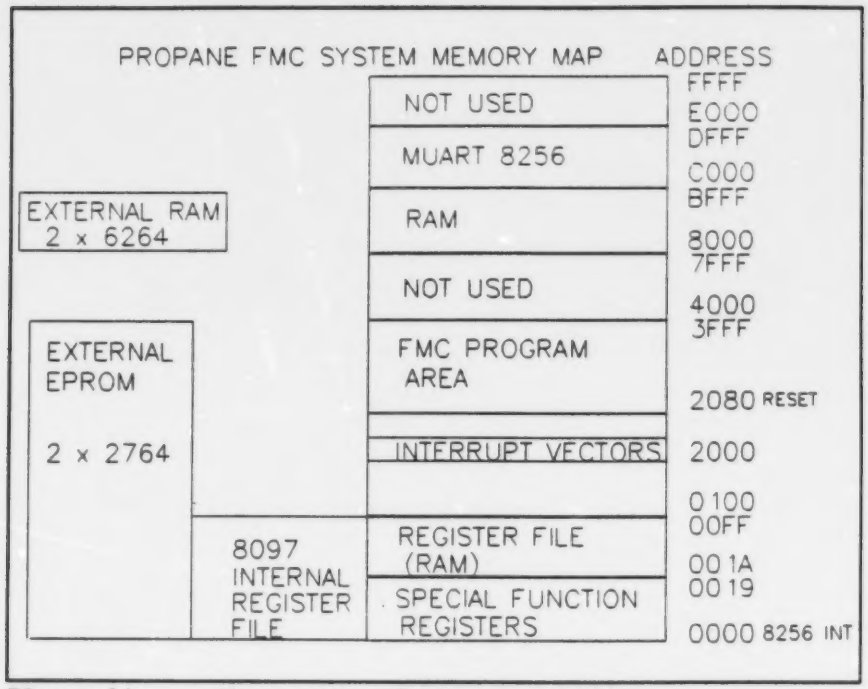

Figure 14. **Memory Map of Micro-controller.**

The control program uses a speed-density open loop control strategy. A multi-dimensional calibration table look up algorithm is used for determining the instantaneous pulse width. Figure 15 shows a three-dimensional map of the optimum pulse width as a function of engine speed and intake manifold vacuum (gauge pressure below that of atmospheric). The base pulse width calibration tables are organized as a single variable function of MAP for a predefined engine speed. A series of similar tables are used to define the pulse width for the whole engine speed range. The instantaneous pulse width is determined by linear interpolation among table values based on the current engine intake MAP and speed. This base pulse width is modified by a coolant temperature dependent multiplication factor to compensate for cold temperature variations. The equation also includes an additive modification factor which is a function of the input from the calibration potentiometer. This feature facilitates manual adjustment of the mixture air-fuel ratio during calibration development. On rapid deceleration as determined from a negative rate of change in throttle displacement and the vehicle speed, extra pulse widths are added to the equation to increase the air-fuel ratio to as high as 25:1. With this feature the fuel consumption is further reduced. The final pulse width used for the current solenoid valve operating cycle is the average value of all the instantaneous pulse widths calculated over the previous cycle.

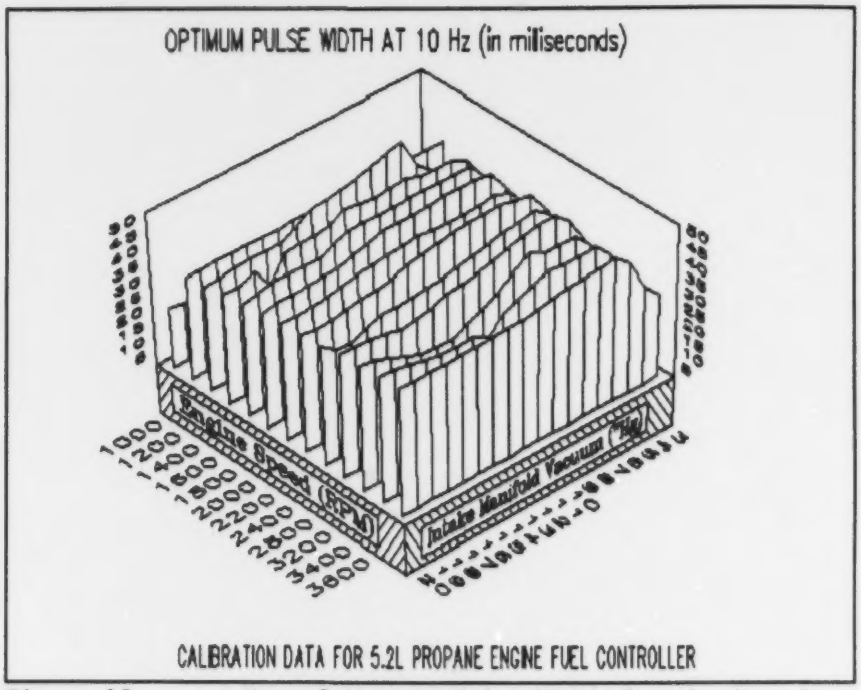

Figure 15. A Map of Optimum Pulse Width for the Open Loop Propane Fuel Metering Control System.

The program is composed of seven code modules. The function of each module is outlined as follows:

1) Monitor module - contains the power up initialization routine, the main loop for determining engine start, run, acceleration, deceleration and idle conditions and switching among various modes of operation. It performs pulse width calculations for the metering solenoid and coordinates the operation of the vent solenoids.

2) Calibration Table Module - contains the calibration data for the system. This data allows the system to be customized to the requirement of a specific engine fuel system configuration. The size of the table values and the number of tables can be readily expanded within the module to accommodate practically any amount of test data available.

3) High Speed Input and Analog to Digital Conversion module - contains interrupt service routines for determining engine and vehicle speeds, performing analog to digital conversion for various engine sensors, and servicing timer overflow.

4) Table Look Up Module - contains routines for reading table values and performing interpolations.

5) High Speed Output Module - contains interrupt service routines for updating average pulse widths and generating a pulse width modulated output for the fuel metering solenoid.

6) Software Timer Module - contains interrupt service routines for sampling instantaneous MAP readings, updating average MAP values and controlling scale switching for the coolant temperature sensor.

7) Serial Communication Module - contains a serial communication routine for diagnostic purposes.

A complete listing of the source codes of the program can be found in Appendix 2.

5.4. Fuel System Calibration Development

There is a distinct relationship between the solenoid valve duty cycle (energized time) and the air-fuel ratio for a given engine carburetion system operating at a given engine operating condition. Initially engine dynamometer test data was used to calibrate the pulse width schedule programmed in the computer. At normal operating conditions, the system was found to be capable of controlling the air-fuel ratio within a repeatable accuracy of ± one half of a ratio. The test vehicle was then tested on road and on the chassis dynamometer to evaluate fuel economy, steady state and transient responses and driveability. The test vehicle was equipped with a strip chart recorder to monitor relevent engine operating parameters as determined by the engine controller. These parameters included vehicle speed, engine speed, MAP, wide range oxygen sensor output voltage, throttle position sensor output voltage, electrical spark ignition timing advance, and coolant temperature sensor reading.

Chart 1 shows an excerpt of engine parameter signals recorded with the strip chart recorder during city cycles 1 and 2 of the CVS fuel economy tests. It provides a comparison of the wide range oxygen sensor output voltage of the three fuel metering solenoid valve configurations including the three solenoid valve, the five solenoid valve and the single solenoid valve packages. A higher voltage reading indicates a leaner air/ratio of the mixture. By examining the instantaneous oxygen sensor voltage in the chart, the difference in transient reponse among various fuel metering system configuations can be identified. The five solenoid configuration had a smaller number of "rich" spikes in the oxygen sensor voltage signal than the three solenoid configuration resulting in reduced fuel consumption, while the single solenoid configuration was the smoothest among all three configurations. As a result of this evaluation process, the

single solenoid configuration was given preference over the three and five solenoid configurations. Using the data collected from the test vehicle, the pulse width calibration was refined for the final fuel metering configuration chosen.

Based on subjective driveability evaluations, no objectionable driveability problems were observed when the vehicle was operated at room temperatures. Engine performance at WOT was good. However, we had observed that the metering system would shift towards a leaner air-fuel ratio at cold temperatures during the warm up period. This condition could be compensated for by using an engine coolant temperature or ambient temperature correction factor to reduce the pulse width.

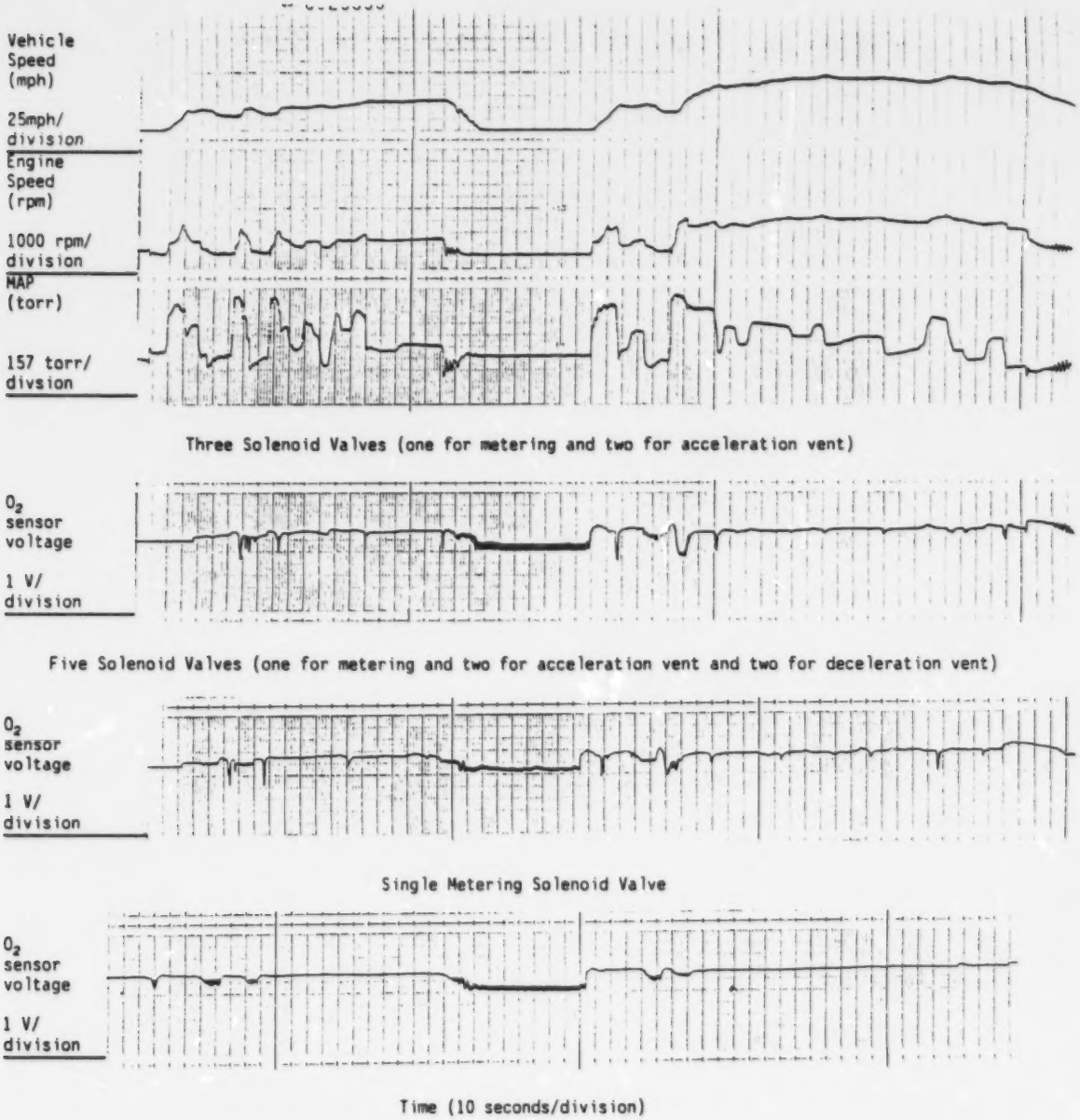
Vehicle Speed (mph)
25mph/ division
Engine Speed (rpm)
1000 rpm/ division
MAP (torr)
157 torr/ divsion
Three Solenoid Valves (one for metering and two for acceleration vent)
O_2 sensor voltage
1 V/ division
Five Solenoid Valves (one for metering and two for acceleration vent and two for deceleration vent)
O_2 sensor voltage
1 V/ division
Single Metering Solenoid Valve
O_2 sensor voltage
1 V/ division
Time (10 seconds/division)

Chart 1. Wide Range Oxygen Sensor Output Characteristics for the Three Solenoid, Five Solenoid and Single Solenoid Configurations of the Computer Controlled Fuel Metering System. Data Obtained from CVS Fuel Economy Tests During City Cycles 1 and 2.

6. FUEL CONSUMPTION COMPARISON

6.1. Outline of Fuel Consumption Comparison Test Procedures

A total of five different carburetion packages were compared for city and highway cycles fuel economy and emissions using CVS test procedures. Three consecutive tests were performed on each package and the test results were averaged. The vehicle was stabilized for a soak period of at least 16 hours at 25°C before testing. All tests were performed at a chassis dynamometer setting of 5000 lbs inertial weight and 17.6 hp road load. Each test started with the city cycles followed by the highway cycles. The first one tested was a standard 1988 5.2 L gasoline production package. It provided a baseline for the comparison. The vehicle was then converted to propane. The first propane system was a typical conventional aftermarket propane conversion package, the second propane package was a conventional aftermarket conversion with oxygen feedback control system. Both of these packages were set up according to the specifications of the manufacturer. The third propane package was Chrysler's 1988 propane production system, and lastly the optimized open loop computer controlled system. A summary of the fuel system set up of each package can be found in Appendix 3.

6.2. Discussion of Test Results

Emission samples from the engine exhaust tap and the tailpipe were monitored during all CVS tests. The fuel consumption values were calculated from emissions data using equations shown in Appendix 4, and the results were summarized in Figure 16. For city cycles, the average fuel consumption of the open loop computer controlled package is significantly lower than that of the conventional aftermarket conversion and the oxygen feedback packages by 8.8% and 10.9% respectively. For highway cycles, the open loop system again shows a reduction in fuel consumption of 5.4% and 8.6% respectively over the conventional conversion and the oxygen feedback packages. When compared to the 1988 production package, the open loop package shows a decrease in average city fuel consumption of 2.3% and no significant difference in average highway fuel economy. The improvement over the conventional aftermarket conversion and the oxygen feedback packages can be attributed to the more precisely controlled air-fuel ratio and spark advance of the open loop fuel metering system. Since the 1988 production package used optimum part throttle spark advance timing and a part throttle lean mixture control system with air-fuel ratio calibrated very close to that for minimum BSFC, the fuel consumption became very similar to the open loop system as evident from the test results.

When the open loop system is compared to the gasoline package on a volumetric basis, the average fuel consumption increases by 20.6% for city and 23.3% for highway. However, if the average fuel consumption is compared on an energy basis, the open loop propane system consumes 12% less energy for city and 10% less for highway (see Appendix 5). This result reaffirms the fact that a well prepared propane fuel package makes more efficient use of available energy.

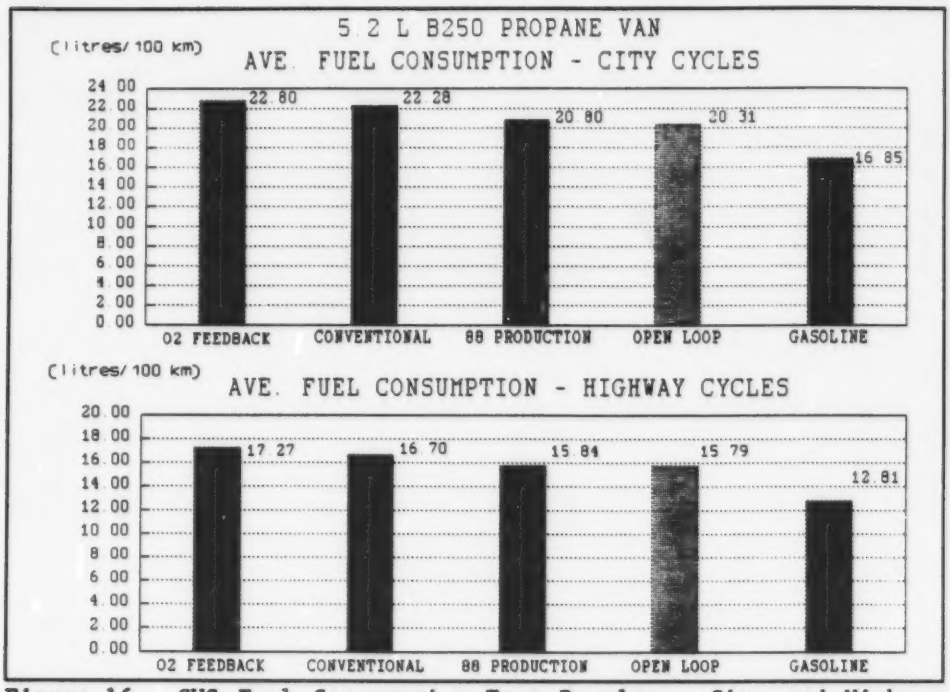

Figure 16. CVS Fuel Consumption Test Results - City and Highway Cycles.

The oxygen sensor output as shown in Chart 2 provides more details on the fuel metering characteristics of each package. The one for the oxygen feedback package indicates an over-rich calibration during transient conditions, especially on decelerations, resulting in poor fuel economy. The one for the conventional aftermarket conversion package shows a lesser degree of fluctuations than the oxygen feedback package, and the positive effect of that is reflected by slightly improved fuel economy. The one for the 1988 production package shows a very stable trace. Together with a calibration that was very close to the optimum for minimum BSFC, the production package resulted in a better average fuel economy than the conventional conversion and the oxygen feedback packages. The open loop system shows a similar stable trace to the production package (see Chart 1). Because of the addition of electronic control features which provided better fuel metering control during transient conditions, the open loop system offered a slight advantage over the production package in city fuel economy.

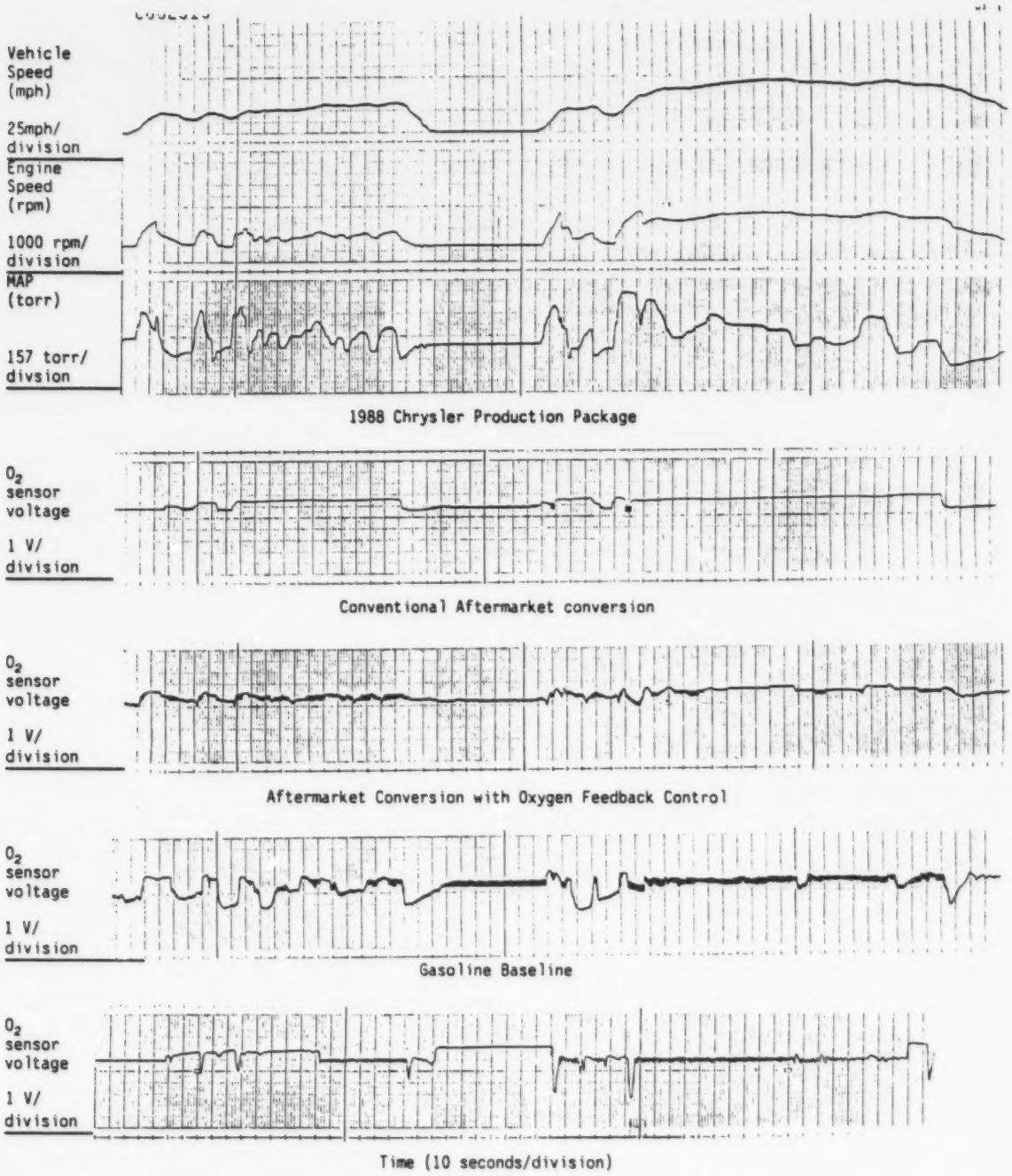

Chart 2. Wide Range Oxygen Sensor Output Characteristics for Various Fuel Metering System Packages Obtained from CVS Fuel Economy Comparison Tests During City Cycles 1 and 2.

Although an exhaust emissions investigation is beyond the scope of this program, the emissions data obtained from the CVS tests does provide some insight into the fuel metering characteristics of each individual fuel package. Figure 17 shows the average equivalent mass emission results for each constituent using engine exhaust modal data. These pre-catalyst results provide a common basis for comparison. As expected, the open loop system displays the least amount of carbon monoxide because of its leaner fuel metering calibration. Emission of oxides of nitrogen of the open loop system is similar to the 1988 production and the oxygen feedback packages but it is 1.9 times higher than gasoline. However, it should be noted that unlike the 1988 production and the open loop systems, the conventional and oxygen feedback systems retained the original EGR (Exhaust Gas Recirculation) system on the vehicle. The oxygen feedback package has a potential for NO_x reduction through the use of a reduction catalyst while the open loop system would have to rely on other means such as EGR. The better fuel efficiency of the open loop system when compared to the gasoline and the other propane packages is also reflected by the lower average carbon dioxide emission. The hydrocarbon emissions of the open loop system are higher than the other propane packages. The modal data showed that this was the result of some trace of incomplete combustion or misfiring that occurred on rapid deceleration when the air fuel mixture was calibrated to be very lean. This was not considered to be a problem because the hydrocarbon emissions level was still lower than that of gasoline, and no driveability problems were encountered.

In summary, the open loop fuel metering system demonstrated significant fuel consumption reductions in the CVS tests over the conventional aftermarket conversions both with and without oxygen feedback control. At the same time, the emission of carbon monoxide and carbon dioxide was reduced considerably. While, the NO_x emissions level remained high compared to gasoline, it was similar to that of the oxygen feedback and the 1988 production propane systems and lower than that of the aftermarket conversion.

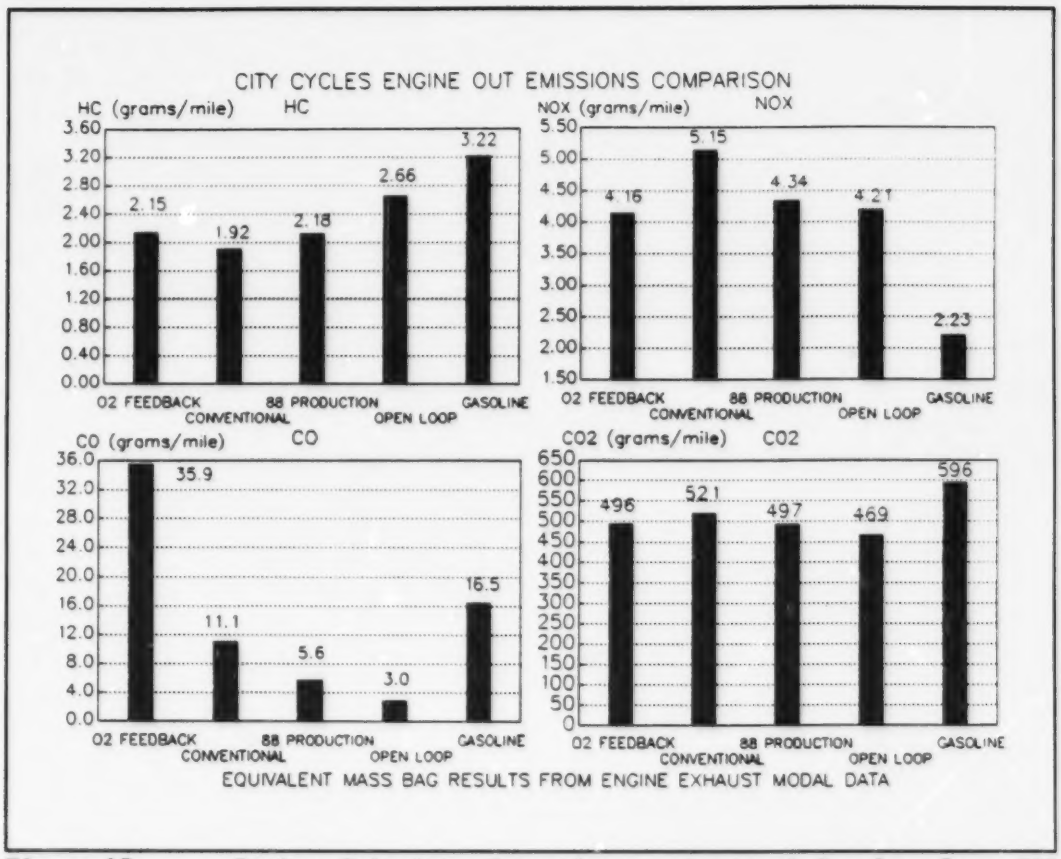

Figure 17. Engine Emissions Comparison - Averaged Results from CVS Tests.

7. CONCLUSIONS AND RECOMMENDATIONS

In the early feasibility study, a propane fuel metering system combining a low pressure gaseous carburetion system with electronic open loop control was considered to be the most practical and cost effective means to improve the fuel efficiency of a propane engine. This case has been proven correct with the demonstration system developed in this program. The findings of the development work are summarized as follows:

(1) Through the redesign of the gas metering valve, the WOT air-fuel ratio of the 5.2 L propane engine was improved to the optimum level which ranged from 14.5:1 to 14.7:1. Together with the improved induction system, the maximum power output increased by 9% over the standard 1988 production propane carburetion package.

(2) From part throttle engine mapping, optimum air-fuel ratio for minimum BSFC was found to occur between 17.5:1 to 20.5:1. This engine map was used as a design target for the fuel metering system.

(3) The open loop fuel metering system was developed and calibrated, and a system configuration using a single metering solenoid valve was found to be the best among several alternatives.

(4) The add-on design of the open loop fuel metering controller is suitable for retrofitting. However, packaging of the electronic control system could be much improved by integrating the control functions into the engine controller as original equipment for factory built vehicles.

(5) From CVS fuel economy testing, the open loop system was found to be significantly more efficient than the conventional aftermarket conversion packages, both with and without oxygen feedback control, showing a reduction in fuel consumption of up to 10.9% in city cycles and 8.6% in highway cycles. Its highway fuel consumption is about the same as the Chrysler 1988 production package with 2.3% improvement in the city cycles.

(6) Engine emissions data from CVS tests indicated that the open loop system emitted a significantly lesser amount of carbon monoxide and carbon dioxides per distance travelled than the gasoline and the other propane packages. Hydrocarbon emissions were less than gasoline but slightly higher than other propane packages. Emission of oxides of nitrogen was higher than that of gasoline but similar to the oxygen feedback and 1988 production systems and lower than the conventional aftermarket conversion.

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APPENDICES

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Appendix 2 A Listing of Source Code for the Propane Fuel Metering Control Program

Appendix 3 A Summary of Fuel System Package Configurations Used in CVS Fuel Consumption Comparison Tests

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Appendix 1

"Alternatives for Advanced Propane Fuel Metering Systems", Interim Report for The Ontario Ministry of Energy, by Chrysler Canada Ltd., March 1986.

SECTION IV

ALTERNATIVES FOR ADVANCED PROPANE FUEL METERING SYSTEMS

BY
CHRYSLER CANADA LTD.

MARCH, 1986

ABSTRACT

This investigation was conducted during the period of October, 1985 through March, 1986 to study potential propane fuel metering technology and identify the best method of demonstrating the benefits of improved fuel metering.

The study shows that most of the benefits of improved fuel metering are derived from advanced electronic control systems, and that only very low pressure gaseous fuel metering systems offer the potential for improvements with these electronic controls without introducing any significant problems over presently available systems.

RÉSUMÉ

Cette étude, qui a été réalisée entre le mois d'octobre 1985 et le mois de mars 1986, avait pour but d'évaluer les possibilités qu'offre la techologie du dosage du propane, en tant que carburant, et de déterminer la meilleure méthode pour démontrer les avantages associés à l'amélioration du dosage du carburant.

L'étude démontre que les systèmes de contrôle électronique perfectionnés sont à l'origine du perfectionnement des systèmes de dosage du carburant et que seuls les systèmes d'injection de carburants gazeux à très faible pression offrent, dans le cas de systèmes électroniques, des possibilités d'améliorations sans toutefois créer de nouveaux problèmes.

EXECUTIVE SUMMARY

This study was conducted to evaluate all possible alternatives for developing improved propane carburetion systems and to identify the best base system to be used in the demonstration of the benefits available through advanced electronic control.

Liquid fuel metering systems have the potential to provide significant power increases over gaseous systems and could offer fuel economy benefits through the use of smaller engines. Unfortunately, major problems associated with metering two phase fuel at high temperatures, low temperature icing, and high cost make it impractical to pursue additional development at this time.

High pressure gaseous fuel metering systems have the potential to reduce cost and improve underhood packaging through more compact components. On the other hand, the high pressure severely restricts low temperature operating capability compared to presently available systems. This may not be a problem in countries with warmer climates but it is a major concern in Canada.

Low pressure gaseous fuel metering systems have superior low temperature performance and have achieved an enviable reputation for reliability. Unfortunately, most of these systems are relatively simple designs with little or no potential for optimization without the addition of electronic control systems.

Electronic control systems have the ability to improve the fuel economy and performance of all of the fuel metering concepts that were reviewed through increased precision and the ability to take inputs from various sensors into account to fine-tune fuel mixtures to the engine's requirements.

This study concludes that some type of electronically controlled low pressure fuel metering system that vaporizes propane at a pressure within approximately 2 psi of atmospheric appears to be the most practical method of providing a worthwhile improvement over existing systems at a reasonable cost, without adding significant operational limitations or problems.

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1. INTRODUCTION

1.1 Overview

Alternatives to present propane fuel metering systems have the potential to provide power, fuel economy, and driveability improvements. The selection of hardware to be used in the development of advanced electronically controlled systems must consider the physical characteristics of propane and the difficulties associated with introducing new technology. In addition, each alternative must be evaluated in terms of packaging, reliability, manufacturability, cost and customer acceptance. The final result should be products that will be welcomed by the market as affordable improvements over presently available products.

To this end, Chrysler Canada Ltd. researched the fundamental operating principles and limitations of all presently available technology. All of this work was intended to evaluate generic limitations rather than the limitations of individual manufacturer's designs. All known existing designs as well as popular design concepts for the future were analyzed.

1.2 Fuel Systems

In the case of propane fuel systems, all methods of fuel metering can be broadly classed into two major groups each of which can be further divided into many subgroups:

Liquid Fuel Metering:
- Throttle Body Fuel Metering
- Plenum Chamber Metering (below the throttle blades)
- Multi-Point Port Metering
- Multi-Point Cylinder Metering

Gaseous Fuel Metering:
- High pressure Gaseous Fuel Metering
- Low Pressure Gaseous Fuel Metering
    - Venturi Systems
    - Mechanically/Electrically Actuated Valve Systems
    - Air Valve Systems

All presently available propane fuel metering systems belong in the category of gaseous fuel metering systems. In these designs, propane is pre-vaporized and then metered into the air flow in the correct proportion. Liquid metering systems have been tried experimentally with limited success but there are no commercially available products at this time.

1.3 Fuel Injection

In the last decade or two, many fuel metering systems have been called "fuel injection" if the fuel delivery pressure is greater than atmospheric pressure. The popularity of these "fuel injection" systems is primarily based on the flexibility provided by advanced electronic control systems. In many cases, otherwise identical systems have been called "fuel injection" or "fuel metering". Many of the systems that were originally called "electronic fuel metering" were renamed "electronic fuel injection" because of the greater sales appeal of this terminology.

In order to prevent terminology from affecting our objectivity and since terminology does not affect performance, we will avoid using the term "fuel-injection" and will simply refer to liquid and gaseous fuel metering systems throughout the rest of this report.

2. LIQUID FUEL METERING

2.1 Overview

The primary incentive for attempting to produce a liquid propane fuel metering system is associated with the power benefit derived from the cooling effect of vaporizing liquid fuel in the intake air stream. The higher charge density and the resulting power increase creates the potential to use a smaller engine for a given application without a loss in power. A small fuel economy benefit is possible with the smaller engine because of the higher load factors. This benefit, unique to liquid fuel metering, is over and above the normal fuel economy benefits associated with advanced electronic control systems.

2.2 Single-Point Metering

Single-Point Metering systems (Throttle Body Metering) usually meter fuel with an intermittent opening and closing of a calibrated orifice above the throttle blades. An orifice of continuously variable size is also possible but more costly.

Electronic control is essential to provide optimum mixtures to the engine with liquid fuel metering. Operation of the control system would be quite similar to that of present gasoline electronic control systems which are usually engine map based systems with manifold vacuum and engine speed as the primary factors used to determine the fuel requirements. As a result of the low specific volume of fuel being metered compared to gaseous metering systems, the size and inertia of the required metering valve is considerably reduced. Feedback control of some form would be essential to provide the required mixture consistency and accuracy to compensate for component variations and wear. Any liquid fuel metering system is inherently more sensitive to part variations since small flow area changes can result in large mixture changes as a direct result of the low flow volume.

The power benefit associated with vaporizing liquid propane in the intake air stream is quite significant. Fuel vaporizing in the air cools the air which would increase the charge density for an unthrottled engine approximately 7% over gaseous metering systems (at an air-fuel ratio of 15.7:1 at 70^{o}F assuming 100% vaporization). The resulting power increase would be roughly proportional.

As a result of the small metering valve size and the fact that a vaporizer is not required, single-point liquid fuel metering also reduces the fuel system space requirements which are at a high premium in todays small 4 cyl. vehicles.

2.3 Multi-Point Fuel Metering

Multi-Point liquid fuel metering systems offer the same advantages as single-point fuel metering and feature a few unique advantages of their own.

Improved cylinder-to-cylinder fuel distribution is possible but not

guaranteed with multi-point systems. It is certainly more easily achieved because it is possible to map the intake system and time the fuel delivery to the best point in the intake stroke. It is always easier to change fuel quantity and timing than it is to modify the manifold structure and configuration. The degree to which distribution is improved depends to some extent on the location at which fuel is introduced into the charge.

Direct cylinder introduction has the potential to increase power output for an unthrottled engine by 4% over conventional gaseous fuel metering systems (at 15.7:1 A/F and 70°F) because no inlet air is displaced by propane. This method has never been used or seriously considered because of the high cost and the problems associated with the extremely high pressures required.

Engine compartment hood clearance is potentially improved by eliminating the requirement for fuel metering devices in the throttle body.

2.4 High Temperature Limitations

The most obvious problem associated with liquid propane metering is the fuel's tendency to change state as a result of an increase in the local temperature anywhere in the fuel lines, or at the fuel metering control valve. At the present time, there is no known means of determining the quality (percent vapour vs liquid) of the fuel being delivered to the metering system. The only way to avoid this problem is to ensure that the fuel is metered as saturated liquid (no vapour present). Since the engine compartment is always warmer than the fuel tank regardless of the ambient temperature, localized boiling must be prevented by using a pump to boost the delivery pressure beyond the boiling point for the highest temperature that will be encountered. Insulating the fuel lines will not eliminate fuel boiling.

For most gasoline engines, carburetion components have design temperatures of 200°F or higher. This temperature is too close to the critical point of propane (203°F / 600psia). In order to guarantee that no vaporization takes place, and provide some margin for pressure regulation, the design pressure for the fuel delivery system would have to be higher than the saturation pressure corresponding to the maximum temperature. Above the critical point, propane is a compressible fluid with a density that varies considerably with small changes in pressure or temperature. As a result, the mass flowrate of propane would be difficult to control. Multi-point systems have even higher design temperatures than throttle body systems which make them even more sensitive to this problem.

These problems can be reduced by locating the metering control valve(s) in a cooler remote location, or by using a dedicated water cooling system separate to the engine coolant to cool the control valves. An alternative system could use propane as a refrigerant by incorporating a separate recirculating fuel circuit with an expansion chamber (evaporator) within (or surrounding) the fuel flow control valve to provide the necessary cooling. These solutions add their own set of problems including loss of control, response lag, complexity, and high

cost. In addition, hot start problems would be encountered because of the delays that occur before cooling systems become effective and the high volume of vapour that would form during a hot soak.

Even assuming that the high temperature problems could be solved in some way, the cost of a high pressure pump could be higher than the cost of obtaining the power increase with a larger engine, increased compression ratio or other means. An 800 psia pump with durability and performance characteristics suitable for automotive applications would likely cost three or four hundred dollars even at "gasoline" volumes. This cost could be much higher if liquid propane lubricity proves to be a significant problem. Fuel metering control valves would also be an expensive proposition above 800 psia.

2.5 Low Temperature Problems

Low temperature operation of liquid fuel metering systems introduces other potential problems. Our experience with motor vehicle operation in the Canadian winter environment dictates that vehicles be capable of starting and running in -20°F ambients without a block heater and down to -40°F with a block heater.

At -20°F without a block heater, liquid propane could absorb very little heat from the metal surfaces in the intake air system and most of the heat required to vaporize the fuel must come from the intake air stream. Any water vapour in the intake air will condense out as a result of the cooling effect of the vaporizing propane. The required theoretical temperature of the intake air stream to prevent water from freezing out of the intake stream with stoichiometric mixtures is approximately 70°F. The resultant charge temperature would be 33°F. Even at these temperatures water would condense out at a rate of 0.012 lbs of water per pound of saturated air.

Gasoline throttle body metering experience has shown that the combination of local fuel vaporization, and pressure drop across the throttle plates, tends to promote water condensation and freezing from the air charge. Freezing water adheres to the closest surface, the throttle blades or shaft, creating potentially unsafe conditions. To prevent this occurrence, preheating the intake air with exhaust manifold heat (anywhere from 70 to 110°F) has been almost universally embraced.

Liquid propane will absorb heat at a much higher rate than gasoline under the same conditions because of its much lower boiling point. As a result, the theoretical intake air temperature required for liquid propane would be considerably higher than that for gasoline. Practical experience with gasoline indicates that the heated air temperature would need to be considerably higher than the theoretical temperature to prevent freezing. In addition, intake air heating would not be effective during the first few minutes of engine operation. Any intake air heating would also reduce the potential power increase associated with liquid propane metering.

Similar icing conditions would be expected downstream in the inlet system if plenum chamber metering were considered.

Both single and multi-point fuel metering systems would likely suffer from metering valve freezing at the valve outlet as a result of the local temperature drop caused by the vaporizing fuel.

2.6 Summary

Significant power increases can be obtained by metering propane as a liquid and vaporizing it in the intake air stream to increase the intake charge density. Unfortunately, the level of intake air heating required to alleviate icing problems would tend to eliminate most of the power benefit.

Liquid fuel metering does not provide inherent fuel economy advantages. However, gains may be possible by taking advantage of the required electronic control system, and by reducing the size of the engine for a given application.

Liquid fuel metering would be a very attractive alternative if it were not for the fact that there is no known method of accurately metering two phase fuel flow and that icing problems are likely to be encountered at lower ambients. Even assuming that these problems could be resolved, it is likely that the cost of such a system would be prohibitive.

3. GASEOUS FUEL METERING

3.1 Overview

All presently available propane fuel systems meter fuel in the gaseous state. The majority of these systems operate at low fuel delivery pressures but the recent popularity of automotive electronic control systems has resulted in the appearance of a few high pressure designs.

The primary incentive for producing high pressure gaseous fuel metering systems is associated with the small size and potentially low cost of metering components compared to other systems with similar performance. Electronic control of such fuel metering components would parallel present gasoline systems and offers the potential to increase fuel economy and performance through improved control of air-fuel ratio.

3.2 High Pressure Gaseous Fuel Metering

There is a great deal of design activity presently aimed at producing high pressure gaseous propane fuel systems that are similar to the present gasoline fuel metering systems. This work is based on the premise that the advantages of the gasoline electronic control system could be readily adapted to propane.

In order to avoid the problems associated with metering liquid or two-phase fuel, propane must be vaporized and metered in the gaseous state. This is usually accomplished by reducing the fuel pressure to some level below the saturation pressure that corresponds to the lowest ambient temperature at which the system must operate. Under these conditions, liquid propane will attempt to vaporize by absorbing heat from its environment. If there is not enough heat available to satisfy the vaporization requirements, then some propane will not change state and will enter the metering system as a liquid and cause severe engine flooding. This is commonly referred to as a "freezup" because of the frost that usually forms on fuel system components when it occurs.

The rate of heat flow for any heat exchange device is directly proportional to the temperature differential across it. For a propane vaporizer, the temperature differential depends on the coolant temperature (usually ambient at engine start following a long soak) and the vaporizer's operating pressure. Since there is a direct relationship between pressure and temperature for propane under normal storage conditions, reducing the operating pressure will reduce the saturation temperature and thereby increase the temperature differential.

In general, Canadians expect to be able to start and run an engine without an engine block heater at ambient temperatures as low as -20°F. At this ambient, the maximum temperature differential that can be achieved in a vaporizer is approximately 23°F assuming that the propane is vaporized at -43°F (saturation at 1 atmosphere). Higher vaporization pressures reduce this differential by approximately 2°F per psi. Low temperature testing of propane vehicles equipped with the best available vaporizers has shown that a 20o differential is marginal for satisfac-

tory performance at -20°F ambients. Any increase in operating pressure would seriously affect the operating capability. For example, operating at 5 psig (-31°F) would penalize the low temperature operating capability by 12°F for both the warmed up operating limit and the cold start limit. An 11 psig system could not be used when the temperature dropped below -20°F and satisfactory start and run without a block heater would require a vaporizer of infinite size.

The benefits of high pressure metering are largely based on the improved control possible with a high speed solenoid valve and the associated control electronics. If the delivery pressure of the gas is reduced to avoid the low temperature problems, the specific volume is increased and a correspondingly larger valve is required to supply a given mass flow of fuel. The response characteristics of electrical metering valves is a function of metering valve mass and the amount of electrical current flowing in the coil windings. Since the current is determined by the solenoid windings and the vehicle control electronics, the mass of the valve becomes the determining factor. Response must be fast enough to give predictable flow characteristics down below two millisecond pulse widths with predictable opening and closing rates of less than one millisecond in order to ensure adequate metering valve performance at high engine speeds. Since the volume flow rate requirement for propane gas is more than 200 times the requirement for an equivalent gasoline "injector", the valve size and mass will be much greater. This will significantly affect the response characteristics of the valve.

Valve size can be reduced by using multiple devices but the least expensive way to reduce size is to increase the delivery pressure. An added advantage of increased delivery pressure is more predictable flow characteristics. Since propane gas is a compressible fluid the mass flowrate through an orifice is a maximum when sonic conditions exist at the nozzle exit. Under these conditions the flow is said to be "choked" and the flowrate is independent of the downstream pressure. Therefore, if the delivery pressure is chosen so that sonic conditions always exist in the metering valve for the lowest ambient that will be encountered, the fuel flow will be governed solely by the "on-time" of the solenoid and the fuel delivery would be much more predictable.

Inevitably, a compromise must be made between low temperature operation and metering valve response and flow predictability. While schemes could be devised to minimize these compromises, e.g. variable pressure regulators, additional cold start/run metering valves, etc., the added complexity of these measures would reduce the potential cost advantage of going to high pressure metering in the first place.

Several other factors must also be considered when designing a metering valve for such a system. Gaseous propane would provide very little lubricating effect to the metering valve's internal components and it is unlikely that an injector designed to meter gasoline could be utilized. High inertial forces associated with the large size and speed of the valve require correspondingly high valve closing forces which could result in unacceptable durability characteristics. Noise levels being transmitted to the passenger compartment could also be objectionable. In addition, fuel system resonance could be a problem with

gaseous flow and careful design would be required to ensure fuel delivery was unaffected by fuel line pressure fluctuations.

Most of the advantages of a multi-point system parallel those for similar gasoline systems. Multi-point systems offer better control of cylinder-to-cylinder fuel distribution, "tuning" of intake charge resonance for improved cylinder filling, better engine compartment hood clearance, etc. The main disadvantage is the added cost and complexity of multiple metering valves.

Uniform cylinder-to-cylinder distribution is not ensured simply because propane is metered as a gas. Intake manifold geometry and flow velocity/turbulence are major contributing factors. Seemingly minor changes to the induction system can have dramatic effects on mixture distribution. Since most propane systems are adapted to existing gasoline vehicles there is a very good possibility that a poorly matched system would result in a distribution pattern that is worse than the gasoline system. Slight changes in throttle body flow or air cleaner location can be detrimental and so in this sense, a port injection system is more desirable due to the minimal induction changes required to adapt it to propane.

3.3 Low Pressure Gaseous Fuel Metering

As a result of the low temperature limitations of high pressure fuel metering systems, all present propane carburetion systems meter propane fuel to the engine in gaseous state at low pressure. They can be generally categorized as three basic types: the venturi, the air valve, and the mechanically driven fuel metering valve.

In the venturi system, properly sized metering jets and openings at the throat area of the venturi nozzle are used to control the flow of fuel in response to the differential pressure signal created in proportion to the air flow. Due to the limited control range of a venturi, additional metering circuits are incorporated in the system in order to meet the idle and wide open throttle fuel requirements of the engine. The accuracy of the system depends largely on the calibration of the metering jets and fuel flow passages and is therefore very sensitive to variations in the mechanical parts. Compensation can be achieved through the use of manually adjustable valves or jets.

Improvement in metering accuracy for venturi based systems can conceivably be made by incorporating an electronically controlled solenoid valve to adjust a secondary fuel supply circuit. This is the basic principle governing operation of typical gasoline electronic feedback carburetors. Alternatively, a pressure regulating valve can be used to vary the air-fuel mixture through adjustment of the fuel supply pressure. In either case, a workable system would require the development of a precise and reliable solenoid valve or fuel pressure regulating valve suitable for integration in a propane venturi carburetion system.

Mechanically operated valve systems use either a mechanical linkage or an electric servomotor mechanism to operate a fuel metering valve in response to one or more engine parameters such as throttle position, air

flow, engine vacuum and speed, etc. Because most of these systems do not generate enough differential metering pressure at the carburetor, they usually require slightly higher metering pressures than other low pressure systems and as a result, low temperature performance sometimes suffers (two degrees fahrenheit per psi above atmospheric). Depending on the design of the particular system, mechanical wear and friction can be a serious problem. Servo motors and sliding or moving mechanical parts exposed to underhood environments are quite often detrimentally affected by dirt and moisture which inevitably find their way into the contact surfaces between moving parts. Winter conditions aggravate this problem by creating a more corrosive environment and by introducing the likelihood of problems associated with freezing moisture that jams the movement of critical parts.

The air valve system uses a fuel metering valve that opens in proportion to the intake air flow. For a given air flow, the air-fuel ratio is primarily controlled by the contour of the metering valve. An additional level of control can be obtained by adjusting the outlet pressure of the vaporizer-regulator upstream of the metering valve. Systems like this are normally designed to operate at very low fuel delivery pressures which considerably extends their low temperature capability compared to other systems.

Electronic feedback systems have been used in conjunction with an oxygen sensor and a solenoid valve to modulate the metering pressure of the vaporizer to achieve stoichiometric feedback control in some of the engine's operating range. While this may work well with respect to reducing exhaust emissions, it is less than ideal in terms of achieving optimum air-fuel mixture for best fuel economy and performance.

A microprocessor based open-loop control system could be implemented to overcome these limitations. The basic mechanical air valve metering system has been proven to be quite reliable, is reasonably consistent, and has good overall performance over a wide range of ambient conditions. Improvements in fuel economy and metering accuracy can be realized by adding an electronic control system to determine the optimum instantaneous air-fuel ratio and to adjust the mechanical metering system accordingly. A solenoid valve can be used to adjust the air-fuel ratio by governing the metering operation of the air valve or by varying the metering pressure. As a result, the desired fuel economy benefit can be realized without having to resort to expensive hardware. The mechanical system will also provide a fail-safe limp-home system in the event of an electronic control system failure.

3.4 Summary

Although high pressure gaseous metering systems may seem very attractive, there are relatively few advantages to be gained by implementing such a system. Low temperature performance would be reduced by approximately two degrees fahrenheit for each psi of increased metering pressure over present systems. The cost and size of lower pressure electrically operated fuel metering valves would probably be greater than present propane fuel system hardware. If the operating pressure is reduced enough to avoid severely limiting the low temperature performance, then the system becomes a low pressure fuel metering system and

all of the control, cost and size benefits are lost because they are dependent on the high operating pressure.

Mechanical low pressure fuel metering systems have been in existence for decades. Some of these systems have fuel economy and performance characteristics that compete well with recent electronically controlled gasoline systems. The low temperature capability of these systems is superior to higher pressure propane fuel systems, but it is marginal compared to current gasoline vehicles. Additional improvements in low temperature operation would only be possible through increases in vaporizer efficiency since the operating pressure is at the physical limit.

In conclusion, all gaseous fuel metering systems can benefit from the use of electronic control systems to improve the accuracy of the fuel metering characteristics in order to achieve a better combination of fuel economy and performance. Compared to other systems, electronically controlled low pressure metering systems offer a significant advantage in that they do not introduce any new problems while significantly improving on the performance of the basic mechanical system.

4. ELECTRONIC CONTROL SYSTEMS

4.1 Overview

Automatic control systems have been successfully incorporated in various automotive components in the past using purely mechanical or analog electro-mechanical devices. With the advent of low cost digital electronics and microprocessors, sophisticated automatic control systems have become affordable.

The modern electronic engine control system is programmed to direct a wide variety of operations including the basic fuel metering function. Sensors are incorporated in the system to monitor various engine parameters and this information is used to determine the system's control outputs. This is typical of an open-loop control system.

In feedback systems, a sample of the output parameter being controlled is "fed back" to the system for verification and correction. As a result, the accuracy of the system improves, assuming the system is designed to avoid unstable oscillations.

4.2 Open-Loop vs Feedback

Feedback fuel metering systems were developed in the 1970's for use with three-way exhaust catalyst emission control systems on gasoline vehicles. Three-way catalysts function best when the air-fuel ratio is at, or extremely close to, stoichiometric. There are two basic reactions that take place in the catalysts: oxidation and reduction. The first reaction to occur is the reduction of oxides of nitrogen to oxygen and nitrogen. This reaction requires the absence of oxygen for maximum efficiency, which means that lean mixtures cannot be used. After this reaction air is pumped into the catalyst chamber and the oxidation of hydrocarbons and carbon monoxide to form water and carbon dioxide takes place.

In currently available conventional feedback systems a switching oxygen sensor in the exhaust manifold signals the engine control system that the mixture is rich or lean by switching on or off, and the control system adjusts the air-fuel ratio towards stoichiometric. Feedback is used to optimize exhaust emissions with three-way catalysts. It does not optimize economy or performance, which require mixtures leaner or richer than stoichiometric under many operating conditions.

It would be ideal if the oxygen sensor were able to provide a feedback signal proportional to the instantaneous air-fuel ratio demanded by the engine throughout its whole operating range. Such sensors are under active development but have not yet been proven to be reliable in the North American environment. At least one imported vehicle is currently using such a sensor, but no domestic manufacturers have used them as yet. For the present, feedback fuel metering control should be limited to stoichiometric mixtures.

Open-loop and feedback operation are often combined in the same fuel metering system. Most present gasoline feedback systems run open loop under WOT and cold start conditions when a rich mixture is desir-

able. In addition, feedback is impossible during the first few minutes of engine operation in low ambient temperatures unless the engine is warm because oxygen sensors require time to heat up before becoming operational. A propane (or gasoline) system could be designed to run open-loop whenever off-stoichiometric operation is required or desireable for fuel ecomomy or power, and could use feedback only as a check when running stoichiometric mixtures.

The principle advantage of conventional feedback is that continuous operation at the stoichiometric air-fuel ratio allows the use of three-way catalysts to meet emissions requirements. Feedback fuel metering systems can also compensate for variations in altitude, air moisture, fuel blends, and temperature.

Feedback systems also provide some compensation for lower cost hardware and component deterioration. This can lead to significant cost savings because the precision of components used in the fuel management system need not be as high in a feedback system.

Unfortunately, continuous operation at stoichiometric mixtures compromises fuel economy and power under many conditions. Steady state highway cruise fuel economy is significantly affected and there will be slight losses in economy in almost all driving modes. Depending on the cylinder-to-cylinder distribution and combustion efficiency, WOT power losses can be considerable. Conventional gasoline feedback systems normally avoid power losses by switching to open-loop operation at full throttle.

The same control techniques can be combined with higher quality components to control the mixture under all operating conditions in an open-loop system. The air-fuel ratio can be set as rich or lean as required to optimize economy, power, and driveability under all driving conditions. Unfortunately, open-loop systems require considerable engine testing to determine the optimum air-fuel ratio for these conditions. An open-loop system is more likely to require initial adjustment and/or periodic readjustment to compensate for wear, part-to-part variations and for optimized operations in extremes of temperature and altitude.

It is possible to combine the best of both systems by designing the system to run open-loop most of the time and use a conventional switching oxygen sensor as a check during the times when stoichiometric operation is specified by the open-loop control system. If the check indicated that the mixture was off-stoich the entire control system could be shifted by the amount required at the point where stoichiometry was required. This adaptive control would provide the required compensation for low cost components, component wear, fuel variations, and changes in temperature, altitude, and humidity. Intermittent feedback would require the same engine mapping for optimum operation as an open-loop system.

In summary, conventional feedback fuel metering systems do not increase economy, performance, or driveability over conventional propane fuel metering systems. However, significant fuel economy increases

under some cruise conditions are possible with electronically controlled open-loop systems. Extensive development and testing is required to determine the full potential of these systems.

4.3 The Rail Concept

The term "rail" describes the basic mixture provided by a fuel metering system without the influence of electronic tailoring controls. Operating a fuel delivery system under the rail principle has two distinct advantages. First, the electronic controls can operate within a smaller range of authority. This improved control implies more accuracy for a given input and less costly components. Second, a mechanical back-up, or limp-home, system is automatically available should the electronics or electrical controls fail.

Since system response is a function of the total range of control, a rail-based design improves system response significantly. The accuracy of the tailoring mechanism depends on the total amount that the system must change to compensate for varying engine demand. Utilizing an unassisted electronic fuel metering system would require the electrical controls to account for not only the full range of engine operating conditions but also be sensitive enough to "fine-tune" the fuel for minute variations in engine demand. A mechanically assisted electronic system on the other hand, would utilize the mechanical system to meter most of the fuel in a very repeatable and predictable manner, while the electronic controls would provide the range of control and sensitivity to account for the "fine-tuning" of the fuel mixture necessary for optimum engine operation.

The cost advantage of a rail based design is also a factor. A wide control range high response system will cost considerably more than a small range system with the same response and accuracy characteristics. The number of additional controls and extra programing overhead required for the unassisted system would also be costly.

4.4 Summary

Microprocessor-based control systems have the potential to provide significant increases in fuel economy and performance through increased control precision. Open-loop operation makes it possible to obtain optimum lean mixtures for cruise fuel economy and rich mixtures for maximum power and driveability. Intermittent feed back operation and wide range oxygen sensors offer the potential to eliminate periodic adjustments and calibration. By incorporating a fuel rail via a mechanical fuel metering system, it is possible to improve fuel metering precision by a significant margin and simultaneously provide cost savings and a reliable limp-home system.

The required electronic controls are standard equipment in most modern vehicles. For the OEM segment, these systems can be adapted to perform the required functions. For the aftermarket, a separate dedicated control system is required that could increase the cost of the total system.

5. PROPOSED ELECTRONIC FUEL METERING SYSTEM

5.1 Overview

The modern automobile is probably one of the most severe applications for electronics. An electronic control system suitable for application in a propane fuel metering system must be durable enough to survive the relatively harsh environment imposed by automotive applications and yet remain versatile enough to be able to provide all of the control functions required by the system.

The control system must have enough memory to accommodate the amount of data needed to each unique operating condition that the engine will likely encounter. Simultaneously, it must accommodate the control programs that define the system operation.

The system must be able to analyze signal inputs from various engine sensors in order to determine engine operating conditions. These sensors may include transducers for sensing engine speed, crankshaft position, intake manifold vacuum, and/or throttle position for engine loading conditions, and thermistors for engine coolant, fuel, and intake air temperatures and, an oxygen sensor if feedback control is found to be desirable and necessary under certain engine operating conditions.

The speed must be fast enough to meet the transient air-fuel mixture requirements of an engine during rapid acceleration and deceleration in order to prevent serious driveability problems.

5.2 Intel 8096

Intel's newest family of single-chip microcontrollers, the 8096 family, offers a very attractive microprocessor-based component group upon which a relatively simple and yet powerful control system can be evolved that will meet all of the above-mentioned functional requirements. The Intel 8096BH will become available in early 1986. It offers an on-chip 8K EPROM. If the whole control program can be fitted into this EPROM, external memory devices can be eliminated and the control system will become very compact. Other features of the 8096 that make it ideal for automotive fuel system control applications include on-chip 10 bit analog/digital conversion, multifunction timers, pulse width modulation output ports, and latching high speed output ports. The 8096 is one of the newest, state-of-the-art single-chip 16 bit microcontrollers available on the market. It was specifically designed for real-time control applications.

5.3 Eletronic Fuel Metering System Design Concept

The basic concept of the electronically controlled propane fuel metering system that we propose to evaluate is quite simple. It makes use of a mechanical propane fuel metering system deliberately calibrated with a rich air-fuel mixture throughout its operating range, so that the mechanical system operating on its own would deliver a richer than optimum mixture at all engine load conditions (rich rail as defined

in 4.3). The electronic control system leans the mixture from the rail until the optimum mixture strength is achieved for a given operating condition. This system demands well defined engine air-fuel mixture requirements for calibrating the control signal, which can be determined by mapping the engine torque output and fuel consumption characteristics on an engine dynamometer under various simulated operating and ambient conditions and through extensive on-road driveability testing. The control signal is then calibrated to meet the established requirements.

5.4 Electro-mechanical System Interface

The Impco propane fuel system is well suited to be used as the basic system in our fuel metering demonstration program. It has been used in Chrysler's production propane vehicles for some time, and has performance characteristics well suited for use in the Canadian environment. In addition, an electronic feedback system using an oxygen sensor for adjusting the air-fuel ratio to stoichiometric has already been adapted successfully by Impco to the basic mechanical system.

The vaporizer-regulator uses a spring loaded vacuum diaphragm valve in the secondary chamber to regulate the supply pressure of vaporized propane to the carburetor. The position of the valve is determined by the differential pressure across the diaphragm with one side vented to air inlet reference pressure, and the other side opened to the carburetor mixing chamber vacuum via the metering valve in the mixer throat. The valve opens to supply more fuel and tends to restore the fuel pressure in the supply line when an increase in the mixing chamber vacuum occurs in response to the opening of the throttle and vice-versa.

A solenoid valve can be added to alter and control the air-fuel mixture of the basic system. It can be used to modulate the reference pressure for the secondary chamber of the vaporizer. For a given configuration, the pressure within the chamber varies in response to the net mass of air flowing out of it, which is proportional to the "on-time" of the solenoid valve. Applying this principle to modulate the reference pressure of the vaporizer to regulate the fuel flow to the fuel metering valve, the change in mixture strength becomes a function of the diaphragm valve opening and is uniquely determined by the duty cycle (pulse width) of the electrical signal that turns on the solenoid valve.

By changing the duty cycle of the pulse signal, the flow of propane vapour into the carburetor mixing valve is changed until the desired air-fuel mixture is obtained.

The high speed output port of the 8096 is ideal for generating digital variable duty cycle signals which can be amplified to drive the solenoid valves. Since solenoid valves usually operate at very low frequencies relative to the execution rate of the 8096, the timer and interrupt features associated with the high speed I/O port can be used to keep track of the switch timing.

5.5 Control Algorithm

The basic control algorithm can be briefly described as follows. The optimum air-fuel mixture variations from the basic control rail will be stored in memory as a multi-dimensional map, with intake manifold vacuum (or throttle position), engine speed, coolant temperature, intake air temperature, etc. as the independent variables and the duty cycle as the dependent variable which in turn uniquely defines the optimum air-fuel ratio.

This map can be organized in the 8096 memory as table values with the base duty cycle defined as a function of intake manifold vacuum and a delta duty cycle (which is to be added to or subtracted from the base duty cycle) defined as a function of engine speed. A series of other duty cycle variables that are a function of fuel, intake air and coolant temperatures, barometric pressure, and/or throttle position could be incorporated to modify the base duty cycle to compensate for variations caused by the effects of these parameters.

Different sets of tables can be used for calculating the duty cycle in different modes of engine operations such as cranking, warm-up, idling, cruising, acceleration, deceleration and under various ambient conditions in order to meet the specific requirements of the engine throughout its whole operating range. Additional sensor inputs such as vehicle speed or transmission gear position can aid the system in selecting the correct mode of control. The various temperature, pressure, analog voltages and/or oxygen sensor inputs can be filtered, conditioned and interfaced to the 8096 through the A/D channels.

With additional software overhead, provision for manual calibration of the duty cycle through an external potentiometer or using an "intelligent" self-calibrating algorithm can be incorporated to compensate for variations and wear in the mechanical hardware. Thus, as the engine operates, the computer collects data from various engine sensors, and through a series of table look-up routines interpolates the required duty cycle.

5.6 Summary

This system combines the proven fail-safe characteristics of the mechanical carburetion hardware and the versatility and powerful control capability of the 8096 to provide a practical system that would offer an improvement in fuel economy at a relatively low system cost.

The methods used could be easily adapted to existing vehicles that are equipped with conventional propane carburetion systems, and offers an opportunity to improve the fuel economy of future OEM vehicles. Of course, extensive engine mapping and testing is required for each vehicle-engine-carburetion system combination on which the system is implemented.

A rail-based electro-mechanical system also offers maximum reliability. In the event of partial system failure, the intrinsically fail-safe mechanical system can operate the engine without leaving the vehicle stranded.

In the future, by making use of the serial and standard parallel I/O ports of the 8096, additional features could be added to include other functions such as on-board diagnostics. If wide-range lean-sensing oxygen sensors become available in time, one could also be integrated into the system for verifying the air-fuel ratio and fine-tuning the duty cycle using feedback control techniques.

SECTION V

AN EVALUATION OF VALVE AND VALVE SEAT MATERIALS FOR PROPANE-FUELED VEHICLES

BY
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ABSTRACT

A developmental test program was conducted to evaluate valve and valve seat materials to reduce exhaust valve seat recession in propane-fueled engines. Engine dynamometer and on-road field vehicle testing was used to evaluate valve seat wear. A machinable valve seat material / hard-iron-faced valve package was developed which reduced exhaust seat wear by 82% as compared to the standard gasoline seats.

RÉSUMÉ

Un programme d'essais rattaché à la mise au point des soupapes et du matériel utilisé dans la fabrication des sièges de soupape dans le but de réduire la récession des sièges de valve d'échappement des moteurs aliméntes au propane. On a eu recours au dynamomètre et à des essais de route pour déterminer l'usure des sièges de valve. Un dispositif de valve usinable recouvert de fer a été mis au point qui réduit l'usure des sièges de valve de 82 % si on le compare aux sièges des moteurs classiques alimentés à la gazoline.

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1. INTRODUCTION

The purpose of this study is to improve valve and valve seat life of propane fuelled engines through the use of upgraded valve and valve seat materials.

Most automotive propane engines are adaptations of gasoline engines and use standard gasoline valves and seats. Because of the reduced lubricating properties of propane, increases in exhaust valve seat wear by a factor of 10 to 20 are common. Increased guide and intake valve seat wear may also occur.

In recent years many automotive engines have been introduced using aluminum cylinder heads. These heads are equipped with valve seat inserts and these inserts are installed and machined on an automated assembly line. Typically the use of a valve seat material with very high hardness for propane, reduces the machinability of the inserts such that the installed valve seats must be ground to final dimension in a costly off- line operation. This study will evaluate the wear characteristics of a wide variety of valve and valve seat materials to develop a valve seat insert which will reduce wear to an acceptable level and be on-line machinable.

To evaluate valve and valve sear wear, engine dynamometer testing using a four-cylinder aluminum headed Chrysler engine was performed. Field confirmation of these results was achieved using four-cylinder mini-vans and six-cylinder full size vans in various high metrage commercial fleets.

2. TEST EQUIPMENT

2.1 Engine and Fuel System

Engine dynamometer testing was performed with both 2.2 L and 2.5 L four cylinder engines using fast burn cylinder heads. The propane fuel system consisted of an Impco VFF 30 fuelock, a Model "E" vaporizer with lean mixture control and a CA-100 mixer calibrated for these engines by Chrysler.

2.2 Test Vehicles

Six Chrysler front wheel drive mini-vans were used for 2.5 L four-cylinder engine field evaluation. These vehicles were equipped with single-fuelled propane fuel systems and propane calibrated electronic spark control computers. These vehicles were put into service with courier, airport express, and expediting fleets. Two 3.9 L six-cylinder full-size Dodge B-250 vans were also used for field evaluation with propane fuel systems and propane calibrated spark control computers. These full-size vans were put into courier and airport express service.

2.3 Dynamometers

A 275 horsepower eddy current engine dynamometer with computer control was used for engine durability testing.

3. TEST PROCEDURES

3.1 Engine Dynamometer Testing

Each test cylinder head was subjected to 100 hours of dynamometer endurance testing as per Schedule DTE 25 shown in Appendix I. Valve tip height measurements, using a special fixture, depth micrometer and engine compression measurements were taken at cylinder head installation, removal and at the 50 hour point. Complete valve and valve seat and valve guide measurements were taken upon buildup and teardown of each test cylinder head. Engines were replaced every 400 hours to ensure test results would not be affected by engine wear. Many engine performance parameters and maintenance items were monitored to ensure the consistency of each test. New engines were run on break-in Schedule SRN 25, shown in Appendix I.

3.2 Field Testing

Test cylinder heads were completely measured upon buildup and teardown. Valve tip height and compression pressures were taken during a mid-point check, usually between 60,000-80,000 km; or when required.

Vehicle logs were kept by the fleets to record maintenance and fuel and oil usage. Vehicle maintenance and metrage accumulation was closely monitored by Chrysler.

New engines were installed at the start of each cylinder head test where required.

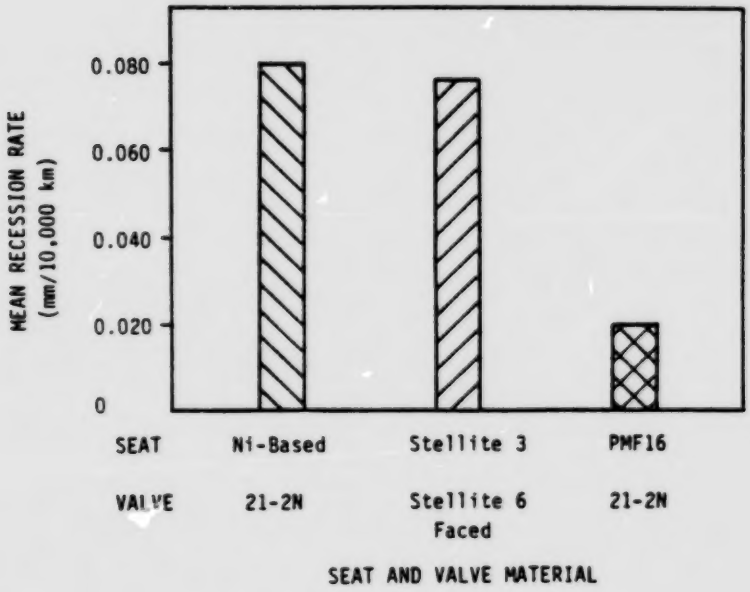
4. BACKGROUND

Chrysler Canada manufactured and sold factory-produced propane vehicles from 1981 to 1988. The 5.2 L propane engine was initially offered with nickel-based exhaust valve seat inserts in place of the induction hardened cast iron seats normally used in the gasoline version of this engine.

Development was initiated to further improve exhaust seat wear in this engine. Cobalt-based exhaust valve seats and exhaust valves with a cobalt-based facing and sintered powdered metal tool steel alloy exhaust valve seats were tested. The powdered

metal tool steel exhaust seats provided a 70-75% reduction in valve seat wear versus the cast nickel-based seats and the cobalt-based seats without the need for a faced exhaust valve. Figure 1 shows comparative wear rates of these inserts.

Figure 1 - 5.2 L Exhaust Valve Recession Rates



Since the 5.2 L gasoline engine does not normally use valve seat inserts, the cylinder head machining line is not equipped to perform the seat installation process. The counterboring operation, installation of the valve seat and final grinding operation is all performed off-line.

Both intake and exhaust valves use positive rotators. Rotators on the exhaust provide more even valve and seat wear with resultant better sealing and less chance of valve burning over the life of the vehicle, with no increase over wear rate over non-rotated valves. Other types of rotation, "minimum" or "free", were shown to increase the chances of valve burning and increased wear rate. Rotators also provide lower guide wear and less chance of stem scuffing on the intake and exhaust by continually changing contact surfaces.

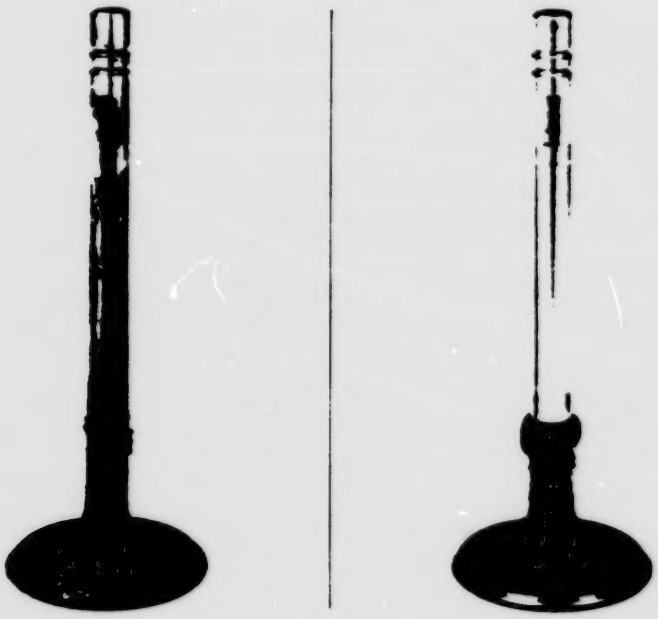
Intake valves are made of Silchrome 1[3] material and have chrome plated stems

(3) Silchrome 1 is a tradename of Allegheny - Ludlum Steel.

for additional scuff resistance. In combination with the positive valve rotator, this package eliminated the sporadic intake valve problems which were experienced in field testing: stem scuffing, guide wear, seat recession, and seat ovality, all leading to poor sealing. Figure 2A shows a typical failure of a non-rotated valve made of a standard low-alloy steel (SAE 1541). Figure 2B shows a production valve of Silchrome 1 material which was rotated with a positive valve rotator.

Figure 2A Typical Propane Intake Valve Failure - 5.2 L Engine

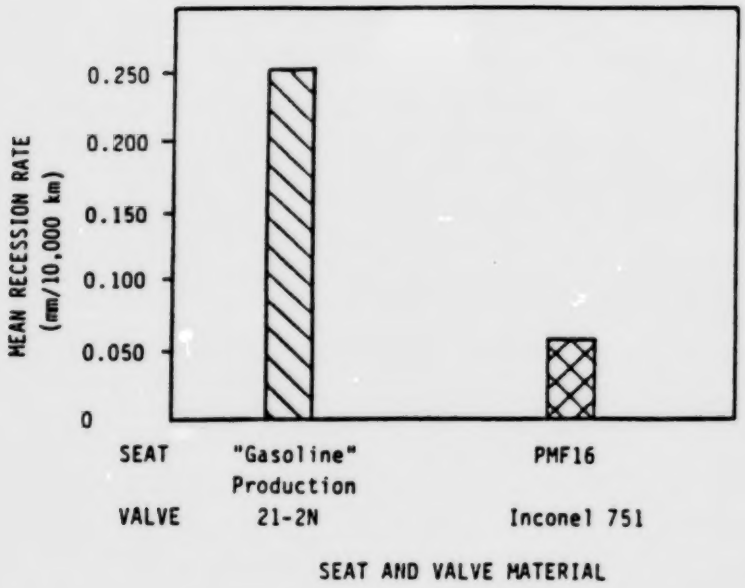
Figure 2B Typical Production Silchrome 1 Intake Valve at 180,000 km-5.2 L Engine



Metrage at failure	= 113,216 km	Metrage	= 180,000 km
Guide Wear	= 0.58 mm	Guide Wear	= 0.06 mm
Seat Ovality	= 0.290 mm	Seat Ovality	= 0.008 mm
Seat Recession	= 0.56 mm	Seat Recession	= 0.00 mm

The 2.2 L four-cylinder engine was used in passenger propane cars from 1982 to 1987. In 1987 the intake and exhaust valve seats were upgraded to the same sintered powdered metal tool steel as used in the 5.2 L engine. Exhaust seat wear rates for the gasoline versus propane exhaust seats, both in truck service, are shown in Figure 3.

Figure 3 - 2.2 L Exhaust Valve Recession Rates



Exhaust valves are of a two-piece design with Inconel 751 (4) heads and chrome-plated 4140 stems. Valve stem seals are also different from gasoline, having 0.15mm less interference fit to provide increased lubrication to the intake and exhaust guides. For the intake, similar low levels of intake guide and seat wear as compared to the 5.2 L engine has been achieved with the use of Silchrome 1 valves, oversize valve stem seals and upgraded seats.

Since the propane valve seats are not machinable on-line with the existing tooling to cut the gasoline inserts, the seats are installed and ground off-line.

(4) Inconel 751 is a tradename of International Nickel Ltd.

5. ENGINE DYNAMOMETER TEST RESULTS

The baseline gasoline four-cylinder valve seats were evaluated against ten (10) upgraded sintered powdered metal valve seats supplied by seven (7) valve seat suppliers from around the globe. Some of the seats tested were in production propane engines in various countries. The chemical compositions of the baseline and upgraded valve seats are shown in Table 1.

The baseline gasoline exhaust seat was tested with the standard gasoline exhaust valve made of 21-2N material. All upgraded seats were first evaluated in Round 1 with a two piece design valve using Inconel 751 head material. This valve material was chosen based on past experience with this valve material to prevent valve face pitting with upgraded valve seats. Exhaust valves of 21-2N with both hard iron and cobalt-based facings and exhaust valves of 23-8N were evaluated in Round 2. Valve and valve facing material specifications are shown in Table 2.

5.1 Round 1 Test Results

Each valve seat material underwent two (2) one-hundred hour dynamometer endurance tests, which in the four-cylinder engine results in eight (8) exhaust valve recession data points for each material. The only exception to this was materials I and J which were only tested on 100 hour and 50 hour tests respectively. These materials were both from the same supplier, who after analyzing the results of the material I, provided valve seats of material J for test.

The test results of Round 1 are presented graphically in Figure 4. The exhaust valve recession of the baseline gasoline material A running on propane is increased approximately 18 times, to .44mm in 100 hours, compared to running on unleaded gasoline with material A. Exhaust valve guide wear was excessive, from 0.13mm to 0.26mm. Intake valve seat recession ranged from nil to 0.38mm, but intake guide wear was minimal. At 100 hours compression was down 20 - 30 psig in some cylinders.

Material C is the sintered powdered metal tool steel used in Chrysler factory propane vehicles. This material reduced the exhaust valve recession by 82% as compared to material A . However, the recession with material C was still more than 3 times greater than baseline material A on unleaded gasoline. Intake recession was lowered, maximum of 0.09mm, but intake and exhaust guide wear was not significantly changed from baseline. Exhaust valve seats and valve faces were smooth and no loss in compression was observed.

Valve seat materials K, I, G, J, B, D did not provide significant reductions in exhaust valve recessions as compared to baseline material A. Material K actually increased recession by 30% to 0.57mm in 100 hours. The Inconel 751 valve faces were severely

TABLE 1

VALVE SEAT INSERT MATERIALS

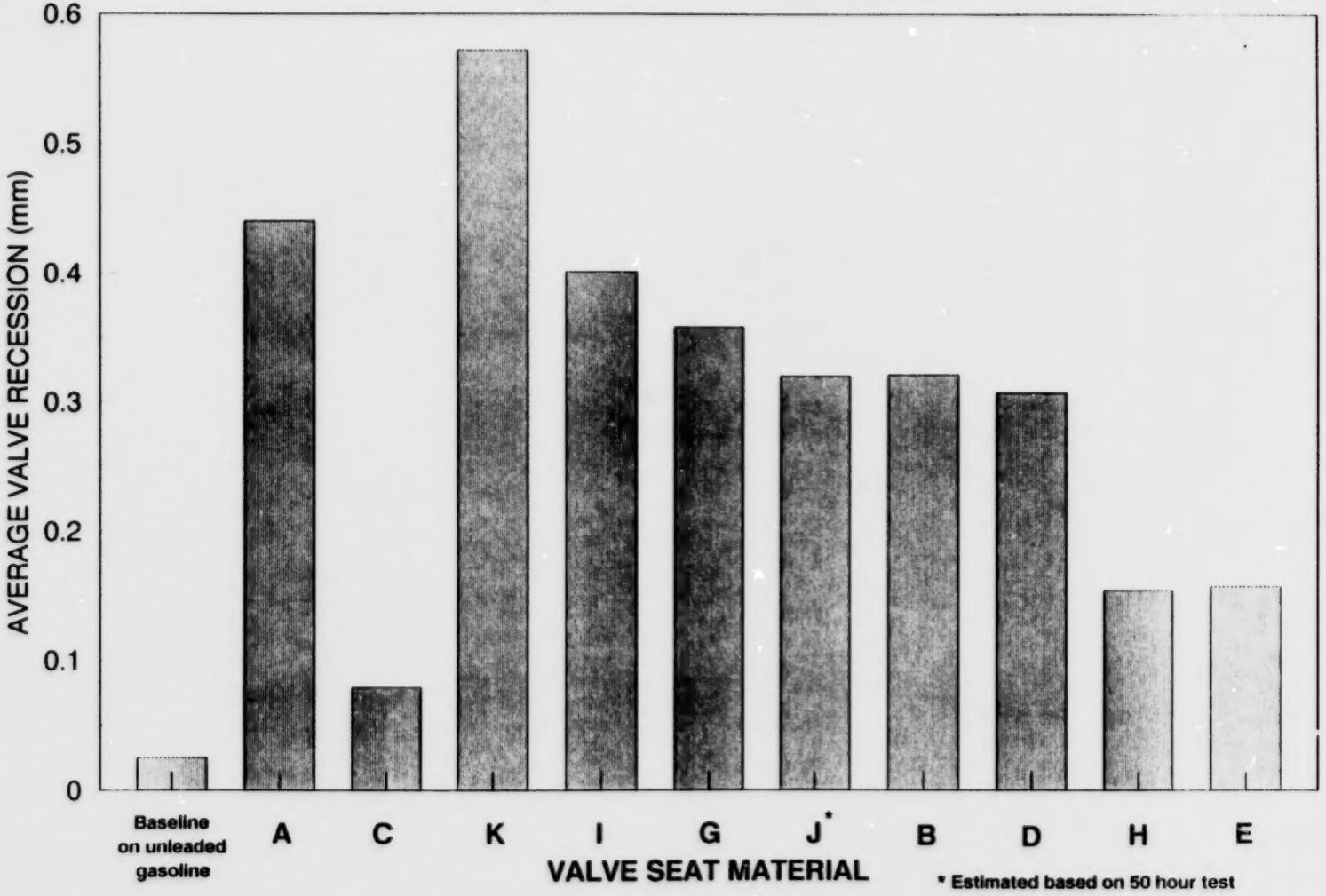
MATERIAL	CHEMICAL COMPOSITION %													Density g/cm^3	Hardness
	C	Cr	Ni	Co	Mn	Pb	Mo	Cu	Si	W	V	Fe	Other		
A	1.8	2.0	0.70	0.40	0.35		0.50 Max	0.50				Bal	0.20 Max. ea. 0.50 Total	7.3	95 HRB
B	1.0	2.0	0.25		0.50 Max		8.0	9.5	0.50 Max	2.90	1.0	Bal		7.4	95 HRB
C	0.9	4.0			0.35		5.0			6.5	2.0	Bal	3.0 S.L. 3.0 Oxides Other 2.0 Max.	6.8	36-44 HRC
D	0.9	4.0			0.35		5.0			6.5	2.0	Bal	3.0 S.L. Other 2.0 Max.	6.7	28-36 HRC
E	0.9	3.25					6.5	20.0		5.0	2.5	Bal	1.0-2.0 Sulphur	7.7	74 HRA
F	0.9	3.25					6.5	20.0		5.0	2.5	Bal	1.0-2.0 Sulphur	7.7	68 HRA
G	0.55	1.6	2.50		1.70		5.0	19.0				Bal	0.75 Sulphur	7.5	35-45 HRC
H	0.68	1.2	1.3	13.5		12.75	5.5		0.36			Bal		8.2	58 HRA
I	1.3	6.75	2.0	6.5			0.55	14.5		2.25		Bal	1.0 Max	7.7	30-40 HRC
J	1.35	7.7	2.05	7.6	1.9		0.48			2.24		Bal	1.0 Sulphur	6.6	88 HRB
K	2.0	35.0	10.0	12.0					5.0			Bal		7.3	45 HRC

TABLE 2

VALVE AND VALVE FACING MATERIALS

MATERIAL	CHEMICAL COMPOSITION %											
	C	Mn	P	S	Si	Cr	Ni	N	Co	Mo	Fe	Other
L (21-2N)	0.55	8.75	0.05 max	0.035 max	0.25 max	20.4	2.13	0.30			bal	
M (Inconel 751)	0.07	0.5 max	0.015 max	0.015 max	0.50 max	15.5	bal		1.0 max	0.50 max	7.0	Ti 2.30 Al 1.23 Ta&Nb 0.95
N (23-8N)	0.33	2.50	0.040 max	0.015 max	0.75	23.0	8.0	0.32	0.50 max	0.50 max	bal	
O (Stellite'F)	1.75	1.0 max	0.030 max	0.030 max	0.115	25.0	22.0	bal	12.0	1.0 max	6.0 max	
P (Hard Iron)	2.25				1.05	24.0	11.0			5.5	bal	

FIGURE 4
EXHAUST VALVE RECESSION
ROUND 1-SEAT INSERT MATERIALS



worn, up to 0.76mm. There appeared to be a strong adhesion between these valve and seat materials causing valve metal to be transferred between the seat and valve smearing the contact surfaces. Intake valve face wear and recession were also excessive, with up to 0.36mm face wear and average recession of 0.39mm.

Material I is a two-layered insert with a hard-layer of material making up the top half of the insert and a lower cost, high heat transfer material for the lower half. A large percentage, 11-18%, of copper is used to improve heat transfer. Exhaust seat recession was only reduced by 9% as compared to baseline. The vendor supplied an alternate experimental material J, which in vendor rig tests reduced wear by 83% as compared to material I. However after only 50 hours of dynamometer testing it was apparent that this material was only capable of reducing wear by approximately 27%.

Material G also contained a large percentage, approximately 16%, of copper. Exhaust seat recession was reduced by only 19%. Intake seat wear was minimal and guide wear was typical. Material B provided a reduction of 28% in exhaust recession. Intake recession was a maximum of only 0.09mm. Material D is supplied by the same supplier as material C and has the same chemical composition as D. The difference between C and D is in the heat treatment process which increases the hardness of C by the formation of cerment type alloy metal oxides and the higher density of material C. It provided a 32% reduction in exhaust wear, although significant intake wear, up to 0.18mm occurred.

Both materials, H and E reduced exhaust valve recession by 64% compared to baseline material A. This wear rate is still approximately 2 times that of material C, but, metallurgical analysis of these two materials indicated that these materials would be machinable with current on-line tooling. Material E was considered to be more machinable than material H.

Material H has a high, 10-15%, concentration of cobalt to form hard particles and is infiltrated with lead, 13-23%. The lead acts as a solid lubricant to reduce wear and increase density to 8.0 - 8.5 g/cc. Exhaust guide wear was a maximum of 0.17mm and intake recession was minimal.

Material E contains no cobalt, but contains 15-20% copper. Exhaust guide wear was a maximum of 0.16mm, but intakes recessed up to 0.11mm. Valve seats and faces were smooth with very little pitting evident.

5.2 Round 2 Test Results

The two best machinable inserts from Round 1, materials H and E, were both further evaluated with different valve and valve facing materials to determine if wear

could be further reduced. The test results of Round 2 are shown graphically in Figure 5.

Exhaust valves of 21-2N faced with cobalt-based material O increased the recession with valve seat materials H and E by 42% and 55% respectively. The cobalt-based facing material was significantly worn,up to 0.18mm with seat material E, but no significant valve face wear occurred with seat material H. Past experience with cobalt-based facing materials were consistent with these recession increases. No pitting occurred on the valve faces. Exhaust guide wear was increased, up to 0.32mm, with material E and was likely the result of hard valve facing particles getting into the valve guide area. No loss of compression resulted from either material.

Hard-Iron valve facing P is a high-carbon austenitic stainless steel developed as a replacement for cobalt-based valve facings for heavy-duty gasoline and diesel engines. Valve seat materials H and E were both tested with 21-2N exhaust valves faced with material P. Valve facing material P did not provide any reduction in recession for seat material H as compared to valve material M, Inconel 751. Some light valve pitting did occur.

However, the exhaust valve recession of valve seat material E was drastically reduced with facing P. This combination reduced wear by 67%, as compared to 751, to only .052mm in 100 hours. This wear rate is even 35% bel w that of sintered powdered metal C . Some valve face pitting was evident but was not excessive.

Valve materials L,(21-2N) and N,(23-8N) were both evaluated to determine if a lower cost, non-faced, valve could be used with seat material E. The recession with these valves were low, but exhaust valve face pitting was significant after 100 hours of testing.

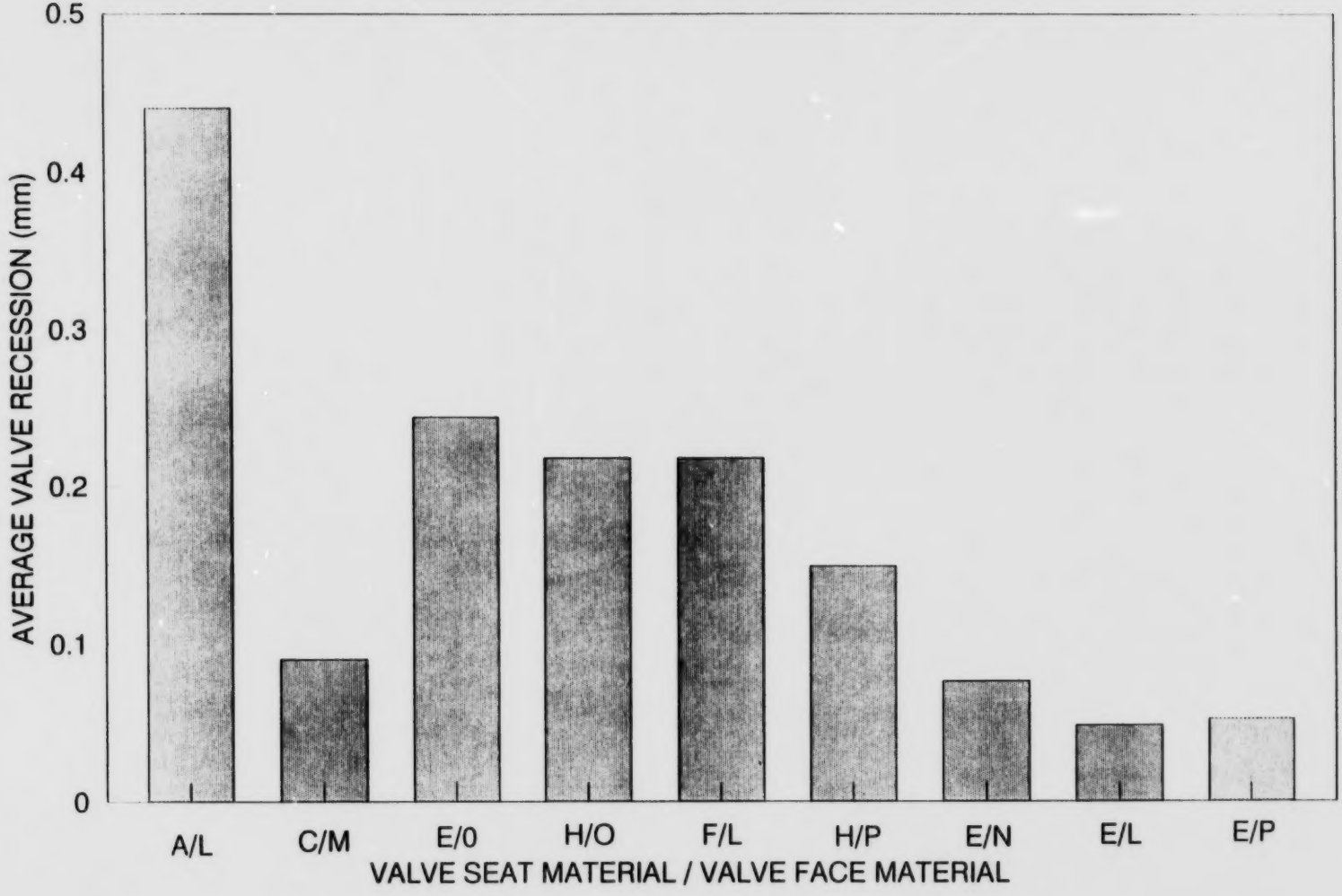
As a final test, seat material F, which is a reduced hardness version of seat material E, was tested with valve material L,(21-2N). This test resulted in recession of .218mm with significant valve face pitting evident.

In summary valve seat material E with exhaust valves of 21-2N faced with material P resulted in a reduction in recession of 88% as compared to baseline material A and did not result in excessive valve face pitting.

6. FIELD TEST RESULTS

Eight vehicles were used for field testing the best two valve and seat packages developed on the dynamometer. These tests were run to approximately 150,000 km in high metrage commercial vehicle service. Past experience with propane vehicle testing indicated that high speed / high load conditions were the most severe for valve and seat wear in propane engines.

FIGURE 5
EXHAUST VALVE RECESSION
ALTERNATE VALVE/FACING MATERIALS



Therefore, the test fleets were selected for their ability to operate in primarily highway type service. The courier type fleets were able to accumulate city-type stop and go metrage during the day and long haul highway metrage at night. The airport express and expedite vehicles were primarily operated on the highway. The vehicle loading was high as the smallest engine available in each vehicle type was used. The F.W.D. mini-vans used 2.5 L four-cylinder engines and the full-size vans were equipped with 3.9 L six-cylinder engines.

6.1 Four-Cylinder Field Test Results

Three vehicles were equipped with sintered powdered metal tool steel, material C, seats and Inconel 751 exhaust valves. The other three vehicles were equipped with material E seats and 21-2N exhaust valves with hard iron facing material P. All vehicles were equipped with Silchrome 1 chrome plated intake valves, over-size valve stem seals and 1988 roller followers and camshafts. All vehicles completed testing with metrages from 131,000km to 175,000km with no exhaust valve or seat failures.

The exhaust valve recession results are summarized in Figure 6. The sintered powdered metal tool steel, material C, seat package reduced recession by 74% as compared to baseline material A. Material E seats and hard iron, material P, valve facing reduced wear by 82% and 32% compared to seat materials A and C respectively. These reductions in exhaust valve seat recession are similar to that found in the dynamometer test results. Some exhaust valve face pitting was found on the material P faced valves, but was not severe enough to result in any loss of function or cylinder pressure and is typical at these high metrages.

Several intake valve guides failed during field testing due to excessive wear. These failures were caused by early prototype roller followers being out of specification causing high valve side loading thus high guide wear. The failed intake guides were repaired and camshafts and followers replaced so that testing could be continued.

6.2 Six-Cylinder Field Test Results

Four sets of 3.9 L cylinders heads were tested to metrages of 150,000 to 223,000 km. Two sets used sintered powdered metal tool steel, material C, seats and 21-2N, material L valves. The other two sets of cylinder heads used material E and 21-2N exhaust valves with material P facing.

The exhaust valve recession results are shown in Figure 7. All recession rates were very low, less than half that of the four-cylinder, possibly due to the reduced engine loading of these six-cylinder powdered full-size vans.

FIGURE 6
FOUR-CYLINDER EXHAUST VALVE RECESSION RATES

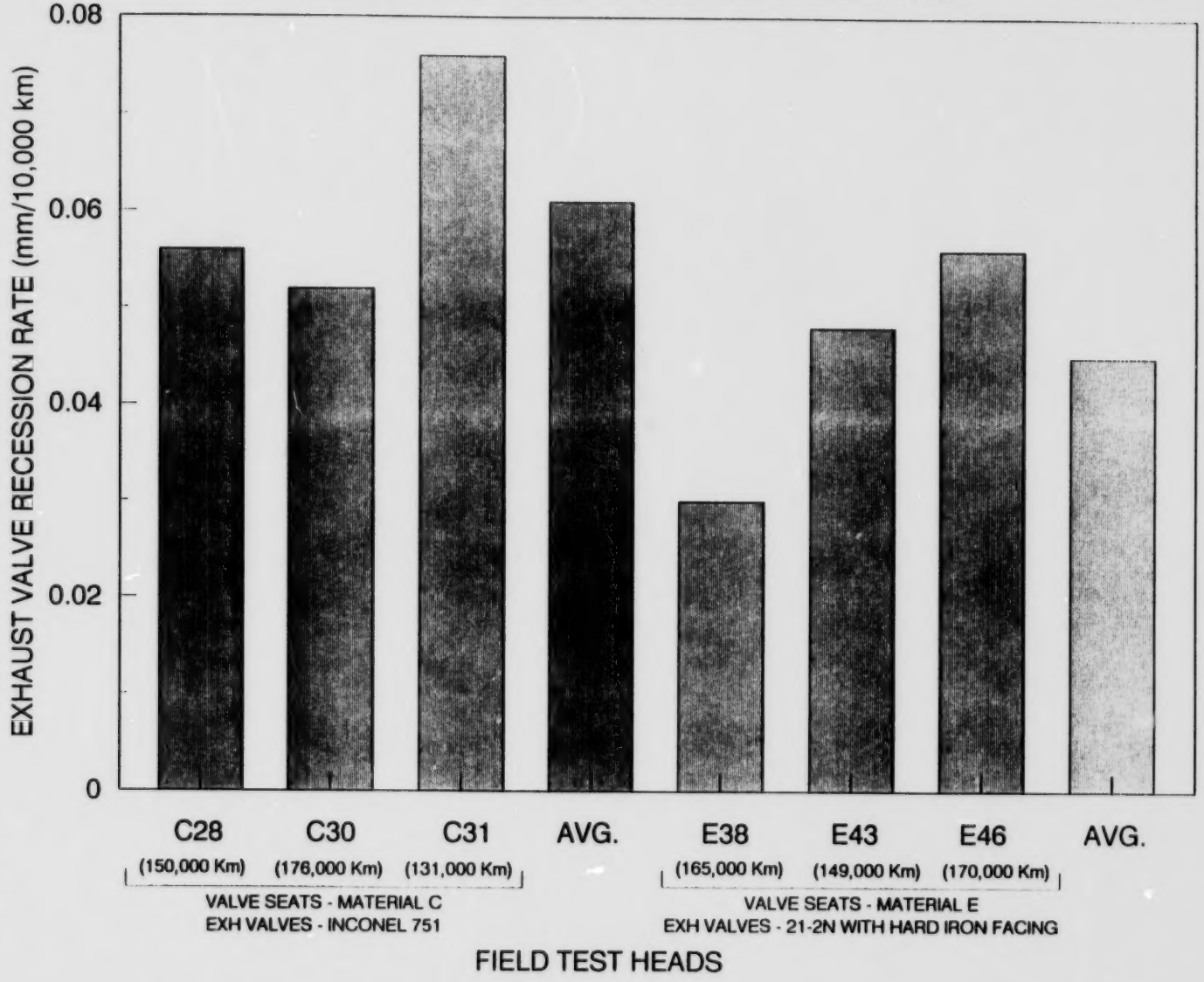
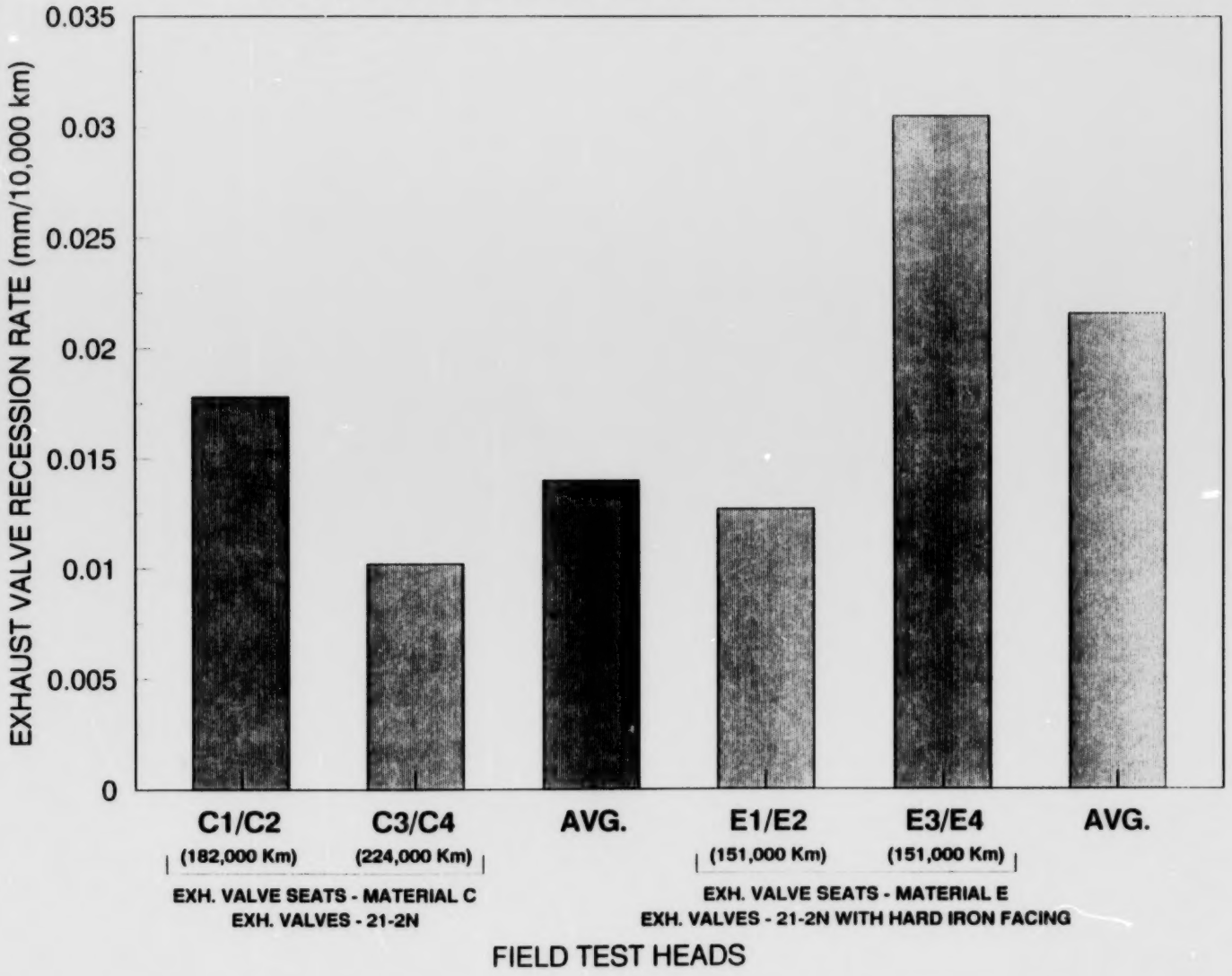


FIGURE 7
SIX-CYLINDER EXHAUST VALVE RECESSION RATES



Cylinder heads E1/E2, C1/C2 and C3/C4 were all run in airport express type service and have similar recession rates. Heads E3/E4 were in courier type service with mixed highway and city usage and resulted in a significantly higher recession rate as compared to E1/E2.

Some exhaust valve face pitting was evident with both seat insert and valve materials, although no loss of compression occurred. Valve guide wear, valve seat runout and valve face wear were not excessive with any of the heads. One intake valve in head E3 did recess excessively, 0.019 inch at 151,000 km, although no loss of compression or other unusual wear occurred.

7. ON-LINE MACHINABILITY

A small machinability trial of material E valve seats in the four-cylinder heads was performed. Eight heads were machined on-line with production C3 class cemented carbide cutting inserts. All seats were successfully machined and excessive cutting insert wear was not observed. To fully evaluate machinability a larger trial is required. The normal tooling life for these cutting inserts is in the 500-700 cylinder head range.

8. CONCLUSIONS

1. Four-cylinder exhaust valve seat wear was increased approximately 18 times with propane as compared to unleaded gasoline.

2. Most upgraded seat materials alone available did not provide a significant reduction in exhaust valve seat wear.

3. A machineable valve seat material/hard-iron faced valve package was developed which reduced exhaust seat wear by 82% as compared to the standard gasoline seats and was superior to sintered powdered metal tool steel seats.

4. Field testing confirmed the durability of the valve seat/valve package in both four and six-cylinder test vehicles.

Appendix I

CHRYSLER 4-CYLINDER PROPANE ENGINE DURABILITY TESTING

I. Test Description

II. Testing Requirements

III. Engine Maintenance

IV. New Engine Break-in Schedule

V. New Cylinder Head Break-In Schedule

VI. Valve Tip Height Measurements

VII. Mechanic Manpower Estimates

VIII. Quotation Requirements

CHRYSLER CANADA LTD.

1985-04-29

I. TEST DESCRIPTION

Testing will consist of up to 2600 hours of engine durability dynamometer testing with a Chrysler propane four-cylinder engine, using an automated controller.

Minimum dyno cell running time is 80 hours per week.

Cylinder heads will be changed approximately every 100 hours and will be delivered by Chrysler, complete with camshaft and rockers.

Engines will be swapped approximately every 400 hours and will be shipped less carburetion and thermocouples.

Valve tip height and compression measurements will be taken at installation and removal of each cylinder head and every 50 hours.

No formal report is required; only completed data sheets and dyno information are required.

The above test schedule estimates may change.

Tentative starting date for engine set-up is June 3, 1985, with testing to start on June 17, 1985.

II. TESTING REQUIREMENTS

1. Use engine oil, engine oil filters and air cleaner elements supplied by Chrysler.

2. Use spark plugs supplied by Chrysler.

3. Coolant temperature to be controlled to 180°F into engine, using a pressurized coolant system.
4. Engine safety shutdown conditions to be:

· coolant temperature:	220°F max., 16 psig max.
· oil temperature:	290°F max.
· oil pressure:	6 psig min., 95 psig max.
· exhaust gas temperature:	1650°F max. for any cylinder
· engine speed	6000 rpm max.

5. Exhaust Back Pressure is to be set at 12 in. Hg at 5400 rpm.

6. If a Chrysler engineer is not present, a daily phone call should be made to Chrysler to report on the day's activities.

7. Any unusual problems with the engine or dynamometer should be reported to Chrysler as soon as possible.

8. A call should be made to Chrysler before any work is performed on the engine.

9. All data sheets to be sent to Chrysler immediately upon completion of each test.

10. A log book is to be kept to record dates and times of test details such as headswaps, engine swaps, test starts, valve tip height measurements and any failures or shutdowns.

11. The following information should be recorded during testing, either continuously or once during each step of the cycle.

- engine rpm
- engine load
- room temperature
- coolant temperature at engine inlet and outlet
- inlet air temperature
- exhaust temperatures at each exhaust port
- manifold vacuum

12. Contact with Chrysler Canada during testing should be done through:

· Jim Lanigan (519) 973-2716

III. ENGINE MAINTENANCE

Engine Oil

Every four (4) test hours, check and record oil level, fill if necessary.

Every fifty (50) test hours, change oil and filter. Check engine oil pressure.

Engine Tune-up Specs.

Every test day, check basic timing and vacuum advance at idle.

Every one-hundred (100) test hours, or every time a cylinder head is changed, change spark plugs.

IV. NEW ENGINE BREAK-IN PROCEDURE

(1) Start-up engine and check for oil pressure.
Check for leaks and any abnormal noises.
Check basic timing and check for operation of governor and vacuum advance (low speeds and loads only).

(2) Run the **ENGINE BREAK-IN SCHEDULE**, SRN 25

(3) Install new cylinder heads.

(4) Break-in cylinder heads according to the "New Cylinder Head Break-in Procedure".

V. NEW CYLINDER HEAD BREAK-IN PROCEDURE

(Engine block already broken-in)

1. Install new cylinder heads with new spark plugs. Measure valve tip heights.

2. Change engine oil and filter.

3. Perform the following Break-in Schedule:

   (a) Run engine at 1000 RPM and 0 ft.-lbs. load for 10 minutes.

   (b) Run engine at 2000 RPM and 35 ft.-lbs. load for 10 minutes.

   (c) Run engine at 3000 RPM and 60 ft.-lbs. load for 10 minutes.

   Check engine for leaks or abnormal noises.

4. Check for:

   - proper oil pressure
   - idle CO% with PCV valve removed
   - W.O.T. CO %
   - Basic Timing
   - Operation of governor and vacuum advance
   - Exhaust Back Pressure

5. Shutdown engine and check dry compression with engine still hot (throttle must be held wide open).

6. Start the **ENGINE DURABILITY SCHEDULE**, DTE 25

   Check engine for leaks or abnormal noises.

VI. VALVE TIP HEIGHT MEASUREMENTS

1. Allow engine to cool for a minimum of eight hours, or until complete engine reaches approximately 25°C.

2. Remove valve cover.

3. Remove camshaft assembly.

4. Attach valve tip fixture to cylinder head and torque bolts to 60 inch-lb.

5. Use Chrysler Canada supplied depth micrometer to measure valve tip fixture to valve tip distance, i.e., valve tip height.

6. Record measurements on Chrysler Canada supplied valve measurement sheets.

7. Reinstall camshaft assembly and valve cover. Use Chrysler supplied gaskets.

8. Start engine and check to ensure proper operation.

VII. MECHANIC MANPOWER ESTIMATES

Measure valve tip heights	2.0 hours
Engine change	12.0 hours
Head change	5.5 hours
Compression check	0.5 hours
Oil change	0.5 hours

These estimates are for manpower planning purposes only.

Fuel Usage

Approximately 30 L per hour.

VIII. QUOTATION REQUIREMENTS

Charges should be broken down into these categories:

1. Engine downtime cell charges per week (if any). This includes engine installed in cell, but no dyno testing being done.

2. Engine running charges per dyno test hour.

   Includes:

   - Fuel cost
   - Data gathering
   - Dyno charges
   - Regular engine checks
   - Supervision

   Does not include:

   - Head/Engine swaps
   - Tip heights

3. Mechanic cost per hour for head/engine swaps and maintenance.

4. Initial Engine Set-up and Instrumentation Cost.

5. Any other additional charges.

6. Any deviations from the requirements set out in this document should be specified.

NOTE: Testing may be terminated at any time by Chrysler Canada Ltd.

SCHEDULE SRN25

NEW ENGINE BREAK-IN SCHEDULE

STEP #	LENGTH HH:MM:SS	THROTTLE POSITION	ENGINE RPM	ENGINE TORQUE
1	00:30:00	PT	3000	23
2	00:30:00	PT	3250	23
3	00:30:00	PT	3500	23
4	00:00:15	ID	3500	0
5	00:30:00	PT	3000	30
6	00:30:00	PT	3500	30
7	00:30:00	PT	4000	30
8	00:00:15	ID	4000	0
9	00:30:00	PT	3000	50
10	00:30:00	PT	3500	50
11	00:30:00	PT	4000	50
12	00:00:15	ID	4000	0
13	00:30:00	PT	3000	63
14	00:30:00	PT	3500	63
15	00:30:00	PT	4000	63
16	00:00:15	ID	4000	0
17	00:30:00	PT	3000	76
18	00:30:00	PT	3500	76
19	00:30:00	PT	4000	76
20	00:30:00	PT	4500	76
21	00:00:15	ID	4500	0
22	00:30:00	PT	4000	81
23	00:30:00	PT	4500	81
24	00:02:00	ID	4500	0
25	00:01:00	ID	0	0

PT - Part Throttle
ID - Idle

Total time for this schedule is: 09:04:15

1985-04-29

SCHEDULE DTE25

ENGINE DURABILITY SCHEDULE

STEP #	LENGTH HH:MM:SS	THROTTLE POSITION	ENGINE RPM	ENGINE TORQUE
1	00:00:30	WO	5400	100
2	00:01:30	ID	5400	0
3	00:00:30	WO	5400	100
4	00:01:30	ED	5400	0
5	00:00:30	PT	4600	60
6	00:01:15	ID	4600	0
7	00:00:15	PT	3200	45
8	00:01:00	ID	3200	0
9	00:00:30	WO	5400	100
10	00:01:30	ID	5400	0
11	00:00:30	WO	5400	100
12	00:01:30	ID	5400	0
13	00:00:30	PT	4600	60
14	00:01:15	ID	4600	0
15	00:00:15	PT	3200	45
16	00:01:00	ID	3200	0
17	00:00:30	WO	5400	100
18	00:01:30	ID	5400	0
19	00:00:30	WO	5400	100
20	00:01:30	ID	5400	0
21	00:00:30	PT	4600	60
22	00:01:15	ID	4600	0
23	00:00:15	PT	3200	45
24	00:01:00	ID	3200	0
25	00:00:30	WO	5400	100
26	00:01:30	ID	5400	0
27	00:00:30	WO	5400	100
28	00:01:30	ID	5400	0
29	00:00:30	PT	4600	60
30	00:01:15	ID	4600	0
31	00:00:15	PT	3200	45
32	00:01:00	ID	3200	0
33	00:00:30	WO	5400	100
34	00:01:30	ID	5400	0
35	00:00:30	WO	5400	100
36	00:01:30	ID	5400	0
37	00:00:30	PT	4600	60
38	00:01:15	ID	4600	0
39	00:00:15	PT	3200	45
40	00:01:00	ID	3200	0

1985-04-29

SCHEDULE DTE25

ENGINE DURABILITY SCHEDULE (CONT'D.)

STEP #	LENGTH HH:MM:SS	THROTTLE POSITION	ENGINE RPM	ENGINE TORQUE
41	00:00:30	WO	5400	100
42	00:01:30	ID	5400	0
43	00:00:30	WO	5400	100
44	00:01:30	ID	5400	0
45	00:00:30	PT	4600	60
46	00:01:15	ID	4600	0
47	00:00:15	PT	3200	45
48	00:01:00	ID	3200	0
49	00:00:30	WO	5400	100
50	00:01:30	ID	5400	0
51	00:00:30	WO	5400	100
52	00:01:30	ID	5400	0
53	00:00:30	PT	4600	60
54	00:01:15	ID	4600	0
55	00:00:15	PT	3200	45
56	00:01:00	ID	3200	0
57	00:00:30	WO	5400	100
58	00:01:30	ID	5400	0
59	00:00:30	WO	5400	100
60	00:01:30	ID	5400	0
61	00:00:30	PT	4600	60
62	00:01:15	ID	4600	0
63	00:00:15	PT	3200	45
64	00:01:00	ID	3200	0
65	00:10:00	WO	4800	100
66	00:02:00	ID	4800	0
67	00:10:00	WO	2800	100
68	00:01:00	ID	2800	0

PT - Part Throttle
ID - Idle
WO - Wide Open Throttle

Total time for this schedule is: 01:19:00

1985-04-29

SECTION VI

MIXED-PHASE WITHDRAWAL FOR COLD STARTING OF PROPANE VEHICLES

BY
CHRYSLER CANADA LTD.

OCTOBER, 1989

ABSTRACT

A study was carried out to evaluate the benefits of using a two-phase (liquid and vapour) fuel withdrawal system as a means of improving the start and immediate drive performance of propane vehicles in cold temperatures typical of northern Canadian winters.

Propane vehicles presently exhibit a tendency to stall if attempts are made to drive off immediately, without a proper warm-up period, at engine coolant temperatures approaching -20°C. A method was developed to feed a two-phase mixture of vapour and liquid to the vaporizer to reduce the heat transfer demands placed on it, and subsequently reduce the cold engine's susceptibility to stalling. The "mixed-phase" concept was evaluated through in-vehicle trials under controlled conditions at Chrysler's vehicle cold test chamber facilities, and on the road during the winter months in northern Ontario and Manitoba.

It was shown that mixed-phase withdrawal could enhance cold engine drive-off performance. However, cold temperature highway driveability appeared to be compromised.

RÉSUMÉ

La présente étude a été réalisée dans le but d'évaluer les avantages présentés par l'utilisation d'un système d'extraction de carburant en phase mixte (liquide et gaz) comme moyen d'améliorer la performance du véhicule alimenté au propane au démarrage et lorsqu'il fonctionne à froid dans les régions glaciales du nord canadien.

A l'heure actuelle, le moteur des véhicules alimentés au propane ont tendance a calé si le conducteur n'attend pas que le moteur se réchauffe avant d'embrayer lorsque la température du fluide de refroidissement atteint la température de -20 ° C. L'on a élaboré une méthode selon laquelle un mélange à deux phases est dosé dans le but de réduire la demande de transfert de chaleur nécessaire réduisant du même coup la susceptibilité de l'engin au calage. La notion de "phase mixte" a été évaluée à l'aide d'essais sur véhicules dans des conditions de contrôle aux installation d'essais de Chrysler et sur la route en hiver dans le nord de l'Ontario et de Manitoba.

Les essais ont démontré que l'extraction en phase mixte pouvait favoriser la performance des véhicules tout de suite après le démarrage. Cependant, le fonctionnement à haute vitesse sur la route par temps froid ne semblait pas aussi bon.

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1. INTRODUCTION

The purpose of this study is to investigate a method to improve the cold temperature start and run performance of propane fueled vehicles.

The cold temperature performance of propane fueled vehicles has been identified as one of their leading deficiencies. During the first few minutes of operation at low temperatures, propane vehicles are susceptible to engine die out or stalling because of the vaporizer's inability to supply sufficient vaporized fuel to the engine. In 1987, Chrysler initiated a study to investigate a method for improving propane cold start and run performance by "mixed-phase withdrawal". This concept entails withdrawing a portion of the propane from the tank as vapour, through an orifice in the withdrawal tube.

The objective is to lower the heat energy requirement of the vaporizer. The design goal is the ability to maintain a fast idle of 2000 rpm after a cold start at -29° C with the fuel tank filled to the 80% level (ie. the maximum fill allowed by law expressed as a percentage of the fuel tank's total water capacity), since testing has shown that if a fast idle can be maintained for at least 2 minutes after starting the engine coolant will have warmed up enough to support light to moderate throttle drive-offs without stalling.

A theoretical model is used to establish a relationship between fuel mass flow, temperature, and orifice diameter and location. System development and performance evaluation is largely through in-vehicle testing under controlled conditions in a cold test chamber and during a winter cold trip to Winnipeg Manitoba.

2. BACKGROUND

2.1 Description of the Problem

With propane as a fuel it is possible to achieve engine cold start performance comparable to contemporary gasoline systems. The ability to keep the engine running is where the propane vehicle's performance often falls short. Present systems deliver liquid fuel to the vaporizer, and the cold engine's ability to keep running after it has started is limited by the vaporizer's capacity to vaporize sufficient fuel to maintain an acceptable fuel/air ratio.

The vaporizer's primary chamber is where fuel line pressure is reduced to approximately 10.3 kPa (1.5 psig) and where heat from the engine coolant is used to vaporize the fuel. The pressure is then further reduced to slightly below atmospheric in a secondary chamber before it is drawn into the mixer/carburetor. If the vaporizer cannot transfer sufficient heat to vaporize the liquid propane in the primary chamber, the chamber will fill with liquid and the engine will die out. After a cold engine stall out it is often very difficult to restart the engine. The liquid propane must be purged from the the vaporizer, either by extended cranking or by evaporation. This evaporation may take several hours at cold ambient temperatures unless an external heat source (such as one or more block heaters) is available.

The first 2 minutes of cold start operation are generally the most critical. If the engine stays running through this period then the coolant temperature will likely be high enough for the vaporizer to function properly under light to moderate loads. Engine fuel demand, as dictated by load or speed, is a very important factor since any increase in fuel mass flow places increased demand on the heat exchanger capacity of the vaporizer.

2.2 Present State-Of-The-Art

For optimum cold starting and operation, a propane fuel system should have the following features:

1) The largest capacity vaporizer possible;
2) Adequate coolant flow to the vaporizer. A dedicated coolant circuit should be utilized so that flow to the vaporizer is maximized;
3) Adequate antifreeze protection;
4) Proper fuel/air ratio and spark advance calibration;
5) Proper idle speed control to maintain the optimum idle speed for all conditions.

A well designed propane system today will provide good cold starting performance with coolant temperatures of -30° C, however, engine stalling may occur on attempts to drive off at temperatures as warm as -20° C. Hence, propane vehicle starting performance compares quite favorably to gasoline, but the inability to keep running presents a serious limitation.

2.3 Some Alternative Solutions

The cold start and run problem can be minimized in small displacement engines by incorporating a higher capacity vaporizer (eg. one intended for large 8 cylinder engines). This is not possible with the larger engines since vaporizers with sufficient capacity are presently not available, and the cost and complexity of using multiple vaporizers makes this option unfeasible.

The use of one or more block heaters will generally overcome the cold start and run problem, allowing operation down to the lowest temperature at which there is sufficient vapour pressure to deliver fuel from the tank. This is not a desirable long term solution to the problem, however, since there are some instances where an electrical outlet for the block heater(s) is not readily available.

An electrical heating element in the fuel line or vaporizer was considered unfeasible because of the excessive energy drain on the vehicle's battery.

The use of two separate and switchable fuel feed circuits, one liquid and one vapour, would add an estimated 40 dollars cost and increase system complexity.

Straight vapour withdrawal creates problems such as tank icing and poor high speed driveability, caused by excessive fuel pressure drop within the tank as all vaporization takes place within the tank, and there is inadequate heat transfer into the tank.

Mixed-phase operation was thought to offer an ideal solution in terms of anticipated performance gains and its estimated cost of 10 dollars.

3. THE THEORY

3.1 The Mixed-Phase Concept

The fundamental principal of mixed-phase withdrawal is to reduce the heat load on the vaporizer by alternatively metering a single or two-phase mixture (vapour or liquid and vapour) from the fuel tank. The percentage of liquid delivered will vary with engine fuel requirements, from 0 at low flow rates to nearly 100% under high demand situations.

This dual mode of fuel delivery is accomplished by utilizing a carefully sized orifice in the fuel withdrawal tube. The orifice is drilled so that it is located in the vapour space above the liquid level in the fuel tank, even when the tank is filled to 80% water capacity (full). Figure 1 illustrates the general configuration of the fuel tank, withdrawal tube, and orifice. Under conditions of low fuel demand there is 100% vapour withdrawal. As demand and the rate of vapour flow through the orifice increase, the pressure drop across the orifice causes the liquid propane to rise in the withdrawal tube until two-phase flow begins.

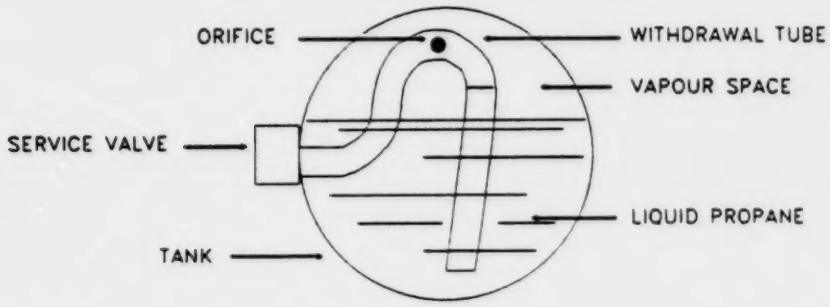


FIGURE 1: The basic configuration of a mixed-phase withdrawal system.

3.2 Fuel Mass Flow

The selection of an optimum orifice diameter requires accurate estimates for engine fuel demand under various conditions of load and speed. Data (torque, rpm, manifold vacuum) from engine dynomometer, and CVS testing was used for preliminary calculations, and indicated that the fuel consumption would lie in the range of 1-2 gm/s at a fast idle of 2000 rpm at -29° C. These bounding values were used to obtain initial estimates for orifice diameter.

3.3 Modelling the System

During the early stages of development the important variables were defined and studied as to how they might affect the feasibility of mixed-phase withdrawal. In this way the major obstacles to success were identified and considered. A theoretical model was constructed to help understand the basic relationship between these variables. Initial calculations and predictions were made on the assumption of steady incompressible flow through a squared edged orifice. This provided a model from which estimates for fuel mass flow could be related to system variables, such as orifice size, fuel level, and fuel density. The following relationship was arrived at through rearrangement of the standard equation of flow through an orifice meter:

$$d_o = [(229 \times 10^6 \times m^2) / (\rho_g \times \rho_f \times h)]^{1/4} \qquad (1)$$

Where:

m = estimated fuel mass flow [gm/s]
d_o = critical orifice diameter [mm]
h = height of liquid column [mm]
ρ_g = density of fuel vapour [kg/m^3]
ρ_f = density of liquid fuel [kg/m^3]

For a given fuel mass flow and temperature (hence density), the height to which the column of liquid rises within the withdrawal tube is inversely related to the diameter of the orifice. If the fuel mass flow rate and orifice height is specified (relative to the liquid level) then we can predict a critical orifice diameter such that the liquid column in the withdrawal tube just rises to the height of the orifice. This would correspond to the onset of two-phase flow. Figure 2 illustrates this relationship in graphical form for three mass flow rates and a liquid column/orifice height of 78 mm (corresponding to a 16 inch tank filled to 80% water capacity).

3.4 Selecting an Orifice

The limits on orifice diameter a are two primary considerations. Too large an orifice will cause a delayed transition to two-phase flow, and might result in problems because of excessive fuel vaporization in the tank. Alternatively, too small an orifice will reduce any potential benefit because of excessive liquid flow. Orifice location was chosen to be as close to the top of the fuel tank as feasible in order to ensure maximum benefit with a full tank.

The system model was used to obtain initial estimates for orifice diameter. The design goal was the ability to maintain a minimum fast idle speed of 2000 rpm after a cold start at -29° C with a full tank. The fuel demand at 2000 rpm was estimated to be between 1-2 gm/s. Figure 2 shows a vapour flow region above the curves and a 2 phase flow region below. From the graph a flow rate of 1 gm/s gives us 6 mm while 2 gm/s gives us 8.5 mm as the critical orifice diameter (onset of two phase flow) at -29° C in a 406 mm (16 in) diameter tank filled to 80% water capacity.

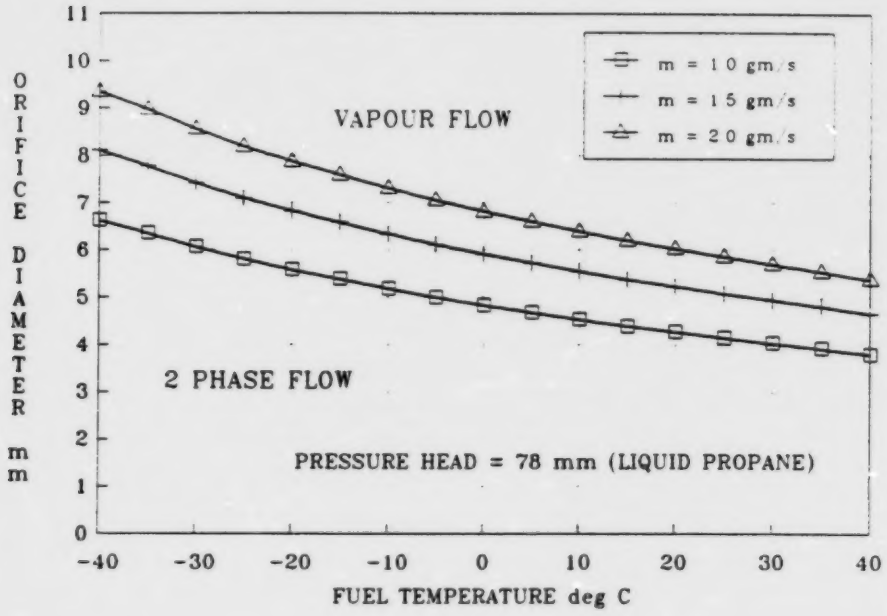


FIGURE 2: System model used to estimate critical orifice diameters.

4. TEST EQUIPMENT AND FACILITIES

4.1 Test Vehicles

Initial development work was carried out using a 1986 Dodge Diplomat equipped with Chrysler's 5.2 L factory propane engine and fuel system. The fuel system incorporated an Impco Model E vaporizer and 225 Mixer.

Special hardware was added to the vehicle for mixed-phase testing. Three service valves were manifolded to the standard 16 inch fuel tank, thus permitting any combination of liquid, vapour, or mixed-phase withdrawal (see Figure 3). Sight glasses were mounted both at the service valve junction outlet at the back of the vehicle, and the fuel-lock inlet at the engine. A removable withdrawal tube was fitted to allow quick changes of orifice diameter. Thermocouples were installed to measure temperatures of: propane in the tank, the tank outer skin, underbody air flow, ambient air, and propane vapour out of the vaporizer. Gauges monitored tank pressure, pressure drop in the fuel lines, engine speed, and engine manifold vacuum.

Other modifications included: a throttle control cable which could be locked, a battery blanket to minimize the likelihood of battery failure during cold room testing, and dual block heaters to expedite starting of stalled engines during cold room tests.

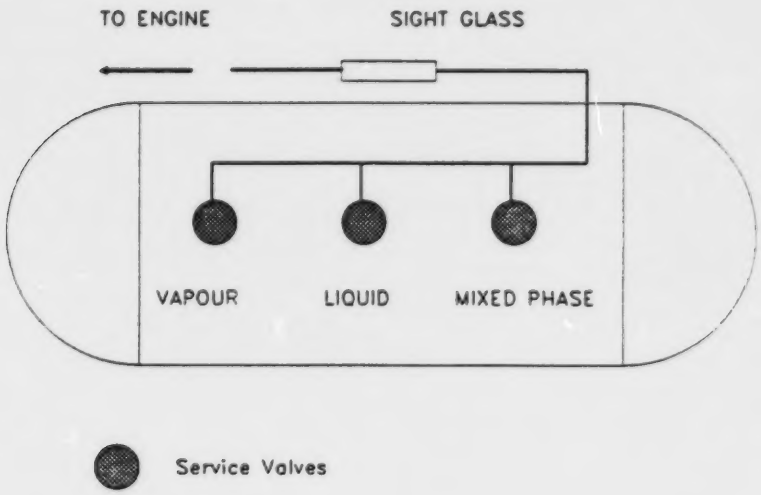


FIGURE 3: Plumbing of fuel lines at the tank for the Diplomat.

The latter stages of cold room and road testing were carried out using two full size vans equipped with the Chrysler 5.2 L factory propane system. These vehicles were also used during the extended cold weather trip to Winnipeg.

Both vans were equipped with manifolded 14 and 10 inch diameter main tanks, each fitted with two withdrawal tubes; one fixed liquid withdrawal, and the other removable so that the orifice diameter could be changed. Both vans were also equipped with 12 inch diameter auxiliary tanks, each fitted with six withdrawal tubes; five fixed (liquid, vapour, 3, 4, and 5 mm orifice) and one removable. Again, the removable tubes were intended to allow quick changes in orifice diameter. The auxiliary tank fuel line plumbing is shown schematically in Figure 4.

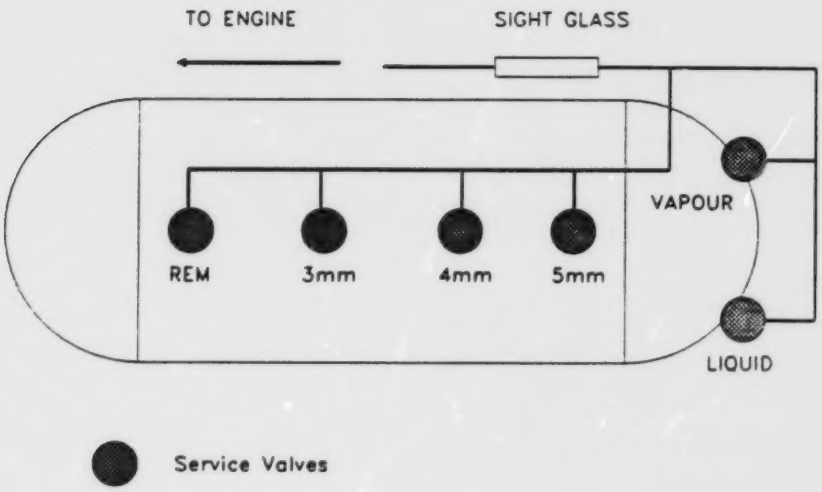


FIGURE 4: Van auxiliary tank fuel line plumbing.

There was a difference between the shape of the withdrawal tube used in the Diplomat and those used in the vans. The withdrawal tubes used in the vans were curved, to more closely approximate the likely final configuration. It was not established whether this difference had a significant effect on system performance. Figure 5 illustrates the difference in shape between the straight withdrawal tube used in the Diplomat and the later, curved tubes used in the vans.

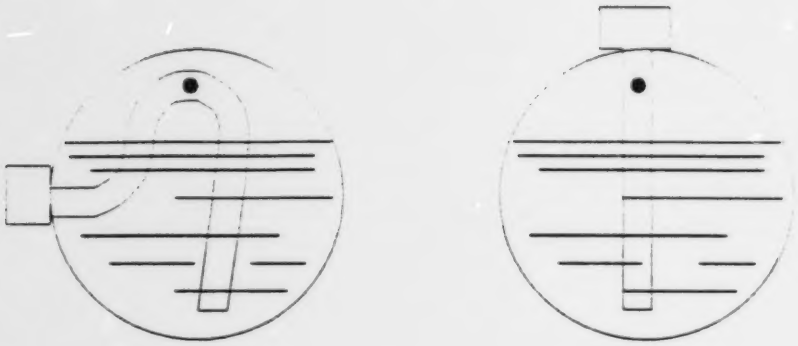


FIGURE 5: Comparison of straight and curved withdrawal tubes.

Three sight glasses were used to observe the propane flow in the fuel lines; one at the auxiliary tank outlet, one about halfway along the auxiliary service line, and one at the vaporizer inlet. The two latter sight glasses were observable from inside the vehicle. Gauges were installed to monitor both tank pressures, vaporizer primary and secondary pressure, engine vacuum, and engine speed. A wide range NTK Universal Exhaust Gas Oxygen Sensor was used to measure the air-fuel ratio. Thermocouples were utilized to measure various ambient, fuel and vaporizer temperatures (ambient air, underbody air, fuel tank skin, liquid and vapour fuel in the tanks, vapour in the dryline, coolant in and out of vaporizer, vaporizer surface temperatures on both the propane and coolant sides, propane and coolant temperatures inside the vaporizer). A synthetic (0W-30) oil was used during the cold trip.

The data acquisition was accomplished via a 24 channel chart recorder and a 22 channel computer controlled data logger.

4.2 Vehicle Cold Test Chamber

Initial cold start/run testing was carried out in Chrysler's vehicle cold test chambers (or cold rooms). Here it was possible to conduct tests under controlled conditions to temperatures as low as -30° C.

4.3 Dynamometers

Engine dynamometer test results were used to calculate estimates for fuel mass flow as a function of engine speed and load. Chrysler's emissions rolls were used to obtain CVS (Constant Volume Sampling) data for verification of fuel mass flow predictions.

5. DEVELOPMENT AND TEST RESULTS

5.1 Cold Start and Run Performance

5.1.1 Vehicle Cold Test Chamber

The primary goal of the cold room testing was to determine if there would be any benefit derived from the mixed-phase system, and to determine a lower bound on orifice diameter.

Vehicle performance was evaluated during the critical warmup phase in the cold room using the following procedure: Each test was preceded by a vehicle soak of at least 12 hours at the temperatures shown. After a successful start and 15 seconds of idle at 800 rpm an attempt was made to maintain 2000 rpm for at least 2.5 minutes (in park). All starts were battery boost assisted to ensure consistent cranking for all tests. The engine oil used was 5W-30.

ORIFICE DIA [mm]	FUEL GAUGE	START [sec]	ENGINE STALLED	TEMP [°C]	COMMENTS
Vapour	5/8	3.0	No	-29	Good start and run.
Vapour	5/8	5.0	No	-29	"
Vapour	4/8	3.0	No	-29	"
Liquid	2/8	4.0	Yes	-29	Good start, stalled at 20 second mark. Could not restart.
Liquid	5/8	4.5	Yes	-29	Good start, stalled at 22 second mark. Could not restart.
6.4	6/8	4.5	No	-29	Good start and run.
6.4	5/8	4.0	No	-29	"
6.4	3/8	3.0	No	-29	"
4.0	8/8	7.0	No	-30	"
4.0	8/8	8.0	No	-31	Initial 8 sec false start. Restart but stall after few sec. idle. Instant restart and good run.
3.2	5/8	7.0	No	-25	Good start and run.
3.2	5/8	3.0	No	-25	"
3.2	4/8	3.5	No	-29	"
3.0	8/8+	40	Yes	-29	Four false starts, would not run at 2000 rpm until the 2 minute mark. Filled to 85% water capacity.
2.0	6/8	3.0	Yes	-29	Good start, stalled at 40 sec.

TABLE 1: A Summary of Cold Room Testing

Baseline tests were conducted on vapour withdrawal to ensure that the ignition system, battery, starter, etc., were operating properly.

Liquid withdrawal tests were carried out to confirm the severity of our test conditions. These liquid tests resulted in stalled engines with no restarts possible, thus confirming that the functional limit for liquid withdrawal was being exceeded. Mixed-phase testing began with a 6.4 mm orifice and progressed with smaller diameters (4.0, 3.2, 3.0, and 2.0 mm) until a lower limit was established, as determined by the vehicle's ability to maintain 2000 rpm without stalling. It was concluded that a 3 mm orifice was close to the lower limit for a full tank.

5.1.2 Cold Trip

Field testing was conducted in Northern Ontario and Winnipeg Manitoba using the two full size vans. The cold start tests were preceded by an overnight soak of 9 to 14 hours at temperatures between -20° C and -30° C. An electric battery warmer and 0W-30 engine oil were used to reduce the stress on the battery during testing. The test procedures and principal results are given below.

Cold start, idle for 20 seconds and then attempt to drive off at part throttle. Attempts to drive off after only a 20 second idle resulted in stalling on liquid withdrawal at temperatures as warm as -20° C ambient (-20° C coolant). With a 3 mm orifice and an 80% fill, drive-off performance began to suffer near -25° C ambient (-23° C coolant); engine sag or stumble was experienced on moderate acceleration at coolant temperatures near -25° C. Engine stalling occurred but quick restarts were possible. The threshold of acceptable performance with the 4 mm orifice appeared to be very close to -25° C (coolant) as well. Therefore, the real world low temperature capabilities did appear to be improved by approximately 3° to 5° C.

Cold start; idle for 20 seconds; run at 2000 rpm for 3.5 minutes before attempting to drive off at part throttle. Given a short 2000 rpm warm up period, the van was still able to drive off at temperatures down to -30° C ambient (-25° C coolant) on liquid withdrawal, and with a 2 mm orifice at an 80% fill level. Therefore, by allowing a 3.5 minute fast idle warmup period the cold temperature capablities appeared to be improved by 5° C as well.

The majority of testing was directed towards establishing a lower limit on orifice diameter for part throttle drive-off after a 20 second idle because this was felt to be the worst case condition. Engine starting did not present a problem, regardless of fuel withdrawal method (liquid, vapour or mixed phase).

The cold room tests are considered to have been more severe. Even though the ambient temperatures at test time were similar, the coolant temperatures were likely warmer during the field tests because of shorter soak times. The soak period in the cold room was at -29° C for 12 hours while ambient temperature in the field may have dropped more slowly overnight. The fact that vehicle restarts were not possible after stalling on liquid withdrawal in the cold room, but were possible in the field, further supports that the cold room test conditions were more severe.

5.2 Cold Weather Fuel Tank Icing

A fundamental concern about withdrawing vapour directly from the fuel tank was whether or not there was sufficient heat transfer into the fuel tank, to support vaporization within the tank without excessive temperature and pressure drop in the tank.

This condition would be aggravated if ice began to form on the outer tank surface because ice acts as a good insulator. Earlier reports of tank icing had been noted especially under conditions of high humidity near 0° C.

Initial road tests were carried out to determine the relative level of tank icing likely to be encountered with liquid, vapour, and mixed phase withdrawal, and to evaluate general driveability. With the full size vans there was concern that since the auxiliary tank was mounted on the side, out of the warm underbody airstream, that this problem would be more prevalent.

Significant icing would only occur with the Diplomat while on 100% vapour withdrawal, under wet or slushy road conditions. After about 3 hours of highway driving a layer of ice about 3 mm thick would form over the lower third of the fuel tank. This condition appeared to be more predominant at higher speeds (higher mass flow rates). The same degree of icing could be duplicated with the van while using a 4 mm orifice in the auxiliary fuel tank. Tank icing was not a problem during the cold trip. The problem appeared to be prevalent only under conditions of high humidity (eg. fog, slight drizzle, light snow), at temperatures near the freezing mark. These conditions were generally not encountered during the cold trip.

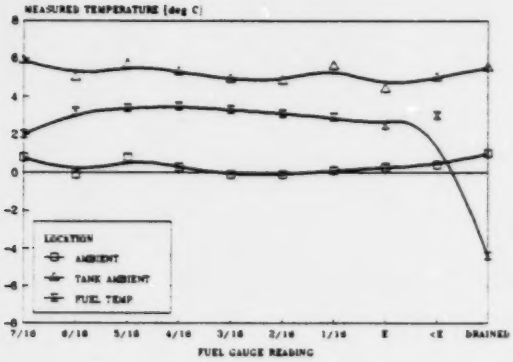
5.3 Cold Weather Driveability

During early testing highway driveability problems were only encountered while on 100% vapour withdrawal. With the Diplomat the ambient, underbody and liquid propane temperatures were nearing -13°, 0° and -21° C respectively (tank pressure had dropped to about 152 kPa) and heavy surging would occur during attempts to maintain speeds over 100 km/hr. Vehicle performance improved only after fuel temperature had risen to about -15° C by virtue of a refueling stop. With the van, even at ambient temperatures near freezing the temperature of the liquid propane in the auxiliary tank gradually dropped to as low as -30° C (pressure dropped to about 83 kPa). As expected, the lesser amount of underbody engine heat flowing past the auxiliary tank was shown to be a predominant factor. No driveability problems were encountered during mixed-phase, or general around-town operation.

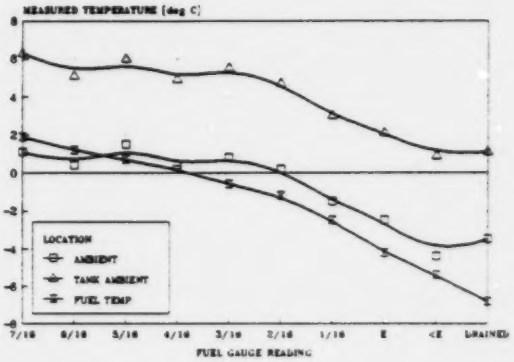
No driveability problems became apparent during the cold trip until ambient temperatures approached -20° C. At this point flat spots or cases of severe surging were experienced, to varying degree, during wide open throttle (WOT) acceleration at highway speeds. This condition was inconsistent in nature, its likelihood of occurring being dependant on fuel temperature (pressure) and factors affecting the percentage of vapour withdrawal (eg. orifice size, fuel level). Generally speaking lower fuel pressures, larger orifices and lower fuel levels aggravate the situation. The flat spots on acceleration were accompanied by a drop in vaporizer primary pressure to 0 psig, indicating a fuel starvation condition.

From the cold start testing it was found that a 3 mm orifice was close to the optimum size to enhance the cold start and run performance of our test vehicles. However, WOT fuel starvation problems were encountered at temperatures as warm as -22° C ambient (-24° C, 152 kPa fuel) with this size. It is suspected that the total fuel system restriction becomes a major factor at lower tank pressures under high fuel demand situations. At -31° C ambient (-26° C fuel, 83 kPa tank pressure) similar WOT hesitation was experienced while on liquid withdrawal as well.

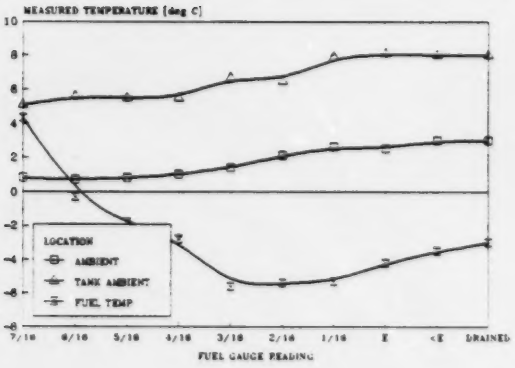
FIGURE 6: Fuel temperature trends at steady highway speeds starting with 25 litres in the auxiliary tank and running to empty using liquid, 3 mm and 4 mm withdrawal.



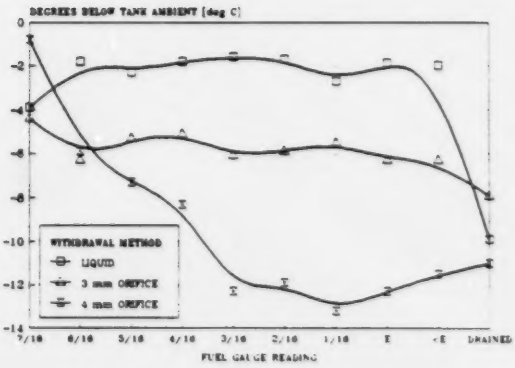
(a) Liquid withdrawal at 110 km/hr.



(b) 3 mm orifice at 80-100 km/hr



(c) 4 mm orifice at 110 km/hr.



(d) Comparison of temperature drops.

It was apparent that driveability problems were closely tied to fuel temperature and pressure in the tank. Operation on straight vapour withdrawal had already been shown to cause problems by excessively lowering the fuel temperature, due to vaporization taking place inside the fuel tank, but it was unknown to what degree mixed-phase operation would do the same.

Part of the cold trip was devoted to monitoring fuel temperature during extended highway cruise conditions. Repeated runs were made with a full size van on liquid, and 3 mm and 4 mm mixed phase withdrawal. The auxiliary tank was filled with 25 litres of fuel, corresponding to a fuel gauge reading of approximately 7/16 full, and run to empty while monitoring ambient, ambient just ahead of the tank, and fuel temperature. Road conditions were dry with ambient temperatures near freezing.

Figures 6a, 6b and 6c show the fuel temperature trends as a function of the indicated fuel level, and the corresponding ambients (measured at the vehicle antennae and just in front of the auxiliary fuel tank). The runs on liquid and 4 mm orifice withdrawal were about 60 minutes long, while the 3 mm orifice test took more time, about 80 minutes, because of the slower average speed. Figure 6d summarizes the results by showing the temperature difference between tank ambient and the fuel temperature during the test period.

From Figure 6d we see that on liquid withdrawal fuel temperature stayed relatively constant at 2° C below tank ambient until the fuel gauge reading approached empty, at which point it quickly dropped off. The sudden temperature drop is attributed to the fact that the fuel level has dropped below the end of the pickup tube (which does not go completely to the bottom of the tank) and consequently 100% vapor withdrawal is taking place. With the 4 mm orifice fuel temperature quickly dropped off to about 12° C below tank ambient at which point it appeared to stabilize. The quick initial drop off with the 4 mm orifice was expected because of the higher percentage of vapour withdrawal. After thermal equilibrium between the tank and ambient was reached (heat transfer into the tank equal to heat being extracted through vaporization) the in-tank temperature leveled off and appeared to follow the trends in the ambients. With the 3 mm orifice the fuel temperature quickly reached equilibrium at about 6° C below tank ambients, and then appreared to drop again as the tank drained.

These steady state temperature trends were consistent with our expectations. Liquid withdrawal showed the least amount of fuel temperature depression at 2° C, mixed-phase withdrawal with a 3 mm orifice produced a 6° C difference, while operation with the 4 mm orifice showed the greatest difference of about 12° C. Initial temperature differences would depend on fuel temperature at the time of refueling while the end portion of the test would be affected by differences in withdrawal tube end to tank bottom distance; this would affect the point at which 100% vapour withdrawal occured.

Since driveability problems were encountered at low fuel temperatures and pressures, any conditions which caused an additional lowering of the fuel temperature was considered undesirable. For example, if the lower limit for satisfactory operation at a steady 110 km/hr on liquid withdrawal was previously -35° C, then this data indicates that the lower limit would be raised by about 12° C to -23° C with the 4 mm orifice. However, we did not carry out similar controlled tests at these very cold ambients to confirm that the same degree of temperature drop would occur at colder ambients.

5.4 Other Observations

The true nature of the fuel flow was observed via the in-line sight glasses during our road tests, and while running on the dyno rolls. Rather than a steady and uniform flow of propane, a surging two-phase flow was seen, except at idle or very light load conditions when only vapour flow occurred. This surging phenomena was originally thought to be caused by cyclic pressure variations in the fuel lines. By this theory, fuel line pressure would drop as all the liquid propane in the lines was consumed, and until tank pressure was sufficient to spill the column of liquid propane over the highest point in the withdrawal tube. This "refilling" of the lines would restore saturated pressure conditions. It was later shown through a simple experiment with water, that this surging could be partly due to the withdrawal-tube-orifice-geometry (orifice size, orifice orientation, and tube shape).

No cases of premature excess flow valve closure were identified during these tests. This was originally thought to be a potential problem due to the change in flow characteristics around the valve.

6. SUMMARY AND CONCLUSIONS

The intent of this study was to investigate the possibility of using a simple mixed-phase withdrawal system as a method of enhancing the cold start and run capabilities of LPG powered vehicles. Testing was carried out using vehicles with Chrysler's 5.2 L engine equipped with the factory propane fuel system. The key results from our testing were as follows:

1) Engines would start at the same minimum temperature regardless of propane feed (liquid, vapour, mixed-phase).

2) Cold room testing confirmed that the liquid withdrawal system could not maintain a 2000 rpm fast idle after a -29° C cold start. For mixed-phase operation the lower limit for orifice diameter, in order that this 2000 rpm fast idle could be held, was found to be approximately 3 mm for the vehicles tested in the cold room.

3) Cold start drive off capabilities improved by about 3° to 5° C with mixed phase operation 3 mm orifice, from -20° C to -25° C coolant temperature. The same level of improvement could be obtained on liquid withdrawal by allowing the engine to warm up at a 2000 rpm fast idle for about 3 to 4 minutes.

4) Tank icing was dependant on tank location (proximity to the warm underbody airstream) but did not cause any problems;

5) Highway driveability problems at low temperatures were found with mixed-phase operation due to lowering of fuel tank temperature and pressure by in-tank vaporization.

The benefits to cold temperature start and run operation must be weighed against the adverse effects on low temperature driveability. A 5° C improvement in cold start and run capability is signifigant, but the potential 5° to 12° C increase on the lower bound for satisfactory performance at highway speeds is not considered to be an acceptable trade off.

APPENDIX II

A LISTING OF SOURCE CODES FOR THE PROPANE FUEL METERING CONTROL PROGRAM

```
SOURCE FILE: A:FMC_MNTR.ASM
OBJECT FILE: A:FMC_MNTR.OBJ
ERR LOC  OBJECT                  LINE        SOURCE STATEMENT
                                    1   $TITLE("FMC_MNTR.ASM: Monitor Module - Propane Metering Controller")
                                    2   ;
                                    3   ;This module performs the following functions:
                                    4   ;-variable declarations
                                    5   ;-initializations of variables and registers,
                                    6   ;-coordinate engine sensors inputs at HSI and AtoD,
                                    7   ;-initiate solenoid controls
                                    8   ;-determine START/RUN modes of operation
                                    9   ;-determine pulse width for solenoid drivers
                                   10   ;-perform MAP transient controls
                                   11   ;
                                   12   ;Link convention: add modules FMC_MNTR.OBJ to FMC.LIB. Extract FMC.LIB
                                   13   ;to FMC.OBJ, run RL96 to obtain FMC.ABS.  Convert FMC.ABS to FMC.HEX
                                   14   ;
                                   15   FMC_MNTR                MODULE  MAIN, STACKSIZE(20)
                                   16   $INCLUDE(8096.INC)
                             =1    17   ;*******************************************************************************
                             =1    18   ;
                             =1    19   ;8096.INC - DEFINITION OF SYMBOLIC NAMES
                             =1    20   ;FOR THE I/O REGISTERS OF THE 8096
                             =1    21   ;(C) INTEL CORPORATION 1983
                             =1    22   ;*******************************************************************************
0000                         =1    23   R0          EQU   00H:WORD      ; R    ZERO REGISTER
0002                         =1    24   AD_COMMAND  EQU   02H:BYTE      ;   W
0002                         =1    25   AD_RESULT   EQU   02H:WORD      ; R
0002                         =1    26   AD_RESULT_LO EQU  AD_RESULT:BYTE; R
0003                         =1    27   AD_RESULT_HI EQU (AD_RESULT+1):BYTE ; R
0003                         =1    28   HSI_MODE    EQU   03H:BYTE      ;   W
0004                         =1    29   HSO_TIME    EQU   04H:WORD      ;   W
0004                         =1    30   HSI_TIME    EQU   04H:WORD      ; R
0006                         =1    31   HSO_COMMAND EQU   06H:BYTE      ;   W
0006                         =1    32   HSI_STATUS  EQU   06H:BYTE      ; R
0007                         =1    33   SBUF        EQU   07H:BYTE      ; R/W
0008                         =1    34   INT_MASK    EQU   08H:BYTE      ; R/W
0009                         =1    35   INT_PENDING EQU   09H:BYTE      ; R/W
000A                         =1    36   WATCHDOG    EQU   0AH:BYTE      ;   W  WATCHDOG TIMER
000A                         =1    37   TIMER1      EQU   0AH:WORD      ; R
000C                         =1    38   TIMER2      EQU   0CH:WORD      ; R
000E                         =1    39   BAUD_RATE   EQU   0EH:BYTE      ;   W
000E                         =1    40   IOPORT0     EQU   0EH:BYTE      ; R
000F                         =1    41   IOPORT1     EQU   0FH:BYTE      ; R/W
0010                         =1    42   IOPORT2     EQU   10H:BYTE      ; R/W
0011                         =1    43   SP_CON      EQU   11H:BYTE      ;   W
0011                         =1    44   SP_STAT     EQU   11H:BYTE      ; R
0015                         =1    45   IOC0        EQU   15H:BYTE      ;   W
0015                         =1    46   IOS0        EQU   15H:BYTE      ; R
0016                         =1    47   IOC1        EQU   16H:BYTE      ;   W
0016                         =1    48   IOS1        EQU   16H:BYTE      ; R
0017                         =1    49   PWM_CONTROL EQU   17H:BYTE      ;   W
0017                         =1    50   IOS2        EQU   17H:BYTE      ; R
0018                         =1    51   SP          EQU   18H:WORD      ; R/W
0000                         =1    52   ZERO        EQU   00H:WORD      ; R/W
```

```
ERR LOC  OBJECT              LINE      SOURCE STATEMENT
                               53  $INCLUDE(8096PUBC.INC)
                             =1    54  ;*************************************************************************
                             =1    55  ;
                             =1    56  ; 8096PUBC.INC - DECLARATION OF SYMBOLIC NAMES AS PUBLIC FOR THE I/O
                             =1    57  ;                REGISTERS OF THE 8096
                             =1    58  ;
                             =1    59  ;*************************************************************************
                             =1    60  ;
                             =1    61  PUBLIC RO,AD_COMMAND,AD_RESULT,AD_RESULT_LO,AD_RESULT_HI,HSI_MODE,SBUF
                             =1    62  PUBLIC HSO_TIME,HSI_TIME,HSO_COMMAND,HSI_STATUS,INT_MASK,INT_PENDING
                             =1    63  PUBLIC WATCHDOG, TIMER1, TIMER2, BAUD_RATE, IOPORT0, IOPORT1, IOPORT2
                             =1    64  PUBLIC SP_CON,SP_STAT,IOC0,IOS0, IOC1,IOS1, PWM_CONTROL,IOS2, SP, ZERO
                                   65  ;
                                   66  ;Variable declarations:
                                   67  ;
                                   68  ;General purpose registers
                                   69  ;
                                   70  PUBLIC  AX,AXL,BX,CX,DX,EX,AL,AH,CL,CH,DL,DH,EL,EH
    001A                           71  RSEG AT 1Ah
    001C                           72          AXL:            DSL     1
    0020                           73          CX:             DSW     1
    0022                           74          DX:             DSW     1
    0024                           75          EX:             DSW     1
                                   76
      001C                         77          AX              EQU     AXL     :WORD
      001C                         78          AL              EQU     AX      :BYTE
      001D                         79          AH              EQU     (AX+1)  :BYTE
      001E                         80          BX              EQU     (AXL+2) :WORD
      0020                         81          CL              EQU     CX      :BYTE
      0021                         82          CH              EQU     (CX+1)  :BYTE
      0022                         83          DL              EQU     DX      :BYTE
      0023                         84          DH              EQU     (DX+1)  :BYTE
      0024                         85          EL              EQU     EX      :BYTE
      0025                         86          EH              EQU     (EX+1)  :BYTE
                                   87  ;
                                   88  ;TIMER_1 variable
                                   89  ;
                                   90  PUBLIC  TIMER_1_HI, HALF_MIN_TIMER
                                   91
    0026                           92          TIMER_1_HI:     DSW     1       ;extended timer1 count
                                   93                                          ;0.131072 second per count
    0028                           94          HALF_MIN_TIMER: DSW     1       ;0.000512 second per count
                                   95  ;
                                   96  ;HSI variables
                                   97  ;
                                   98  PUBLIC  RPM_PERIOD_90, VEH_SPD_PRD, SPD_CONV_CONST, PERIOD_TEMP
                                   99  PUBLIC  RPM_OLD_TIME_LO,RPM_OLD_TIME_HI,VEH_SPD_OLD_TM_LO
                                  100  PUBLIC  RPM, MPH, VEH_SPD_OLD_TM_HI
                                  101  PUBLIC  HSI_D_AVAIL_FLAG, IOS0_BAK, IOS1_BAK, MODE_FLAG
                                  102
    002C                          103          RPM_PERIOD_90:      DSL     1  ;time lapsed between every 90
                                  104                                         ;degree
    0030                          105          VEH_SPD_PRD:        DSL     1  ;time period of SPEED pulse
    0034                          106          SPD_CONV_CONST:     DSL     1  ;conversion factor for MPH & RPM
    0038                          107          PERIOD_TEMP:        DSL     1  ;temperary speed period register
                                  108
    003C                          109          PW_FMS:             DSL     1  ;fuel metering solenoid pulse
                                  110                                         ;width register
                                  111
    0040                          112          RPM_OLD_TIME_LO:    DSW     1  ;time at which previous positive
    0042                          113          RPM_OLD_TIME_HI:    DSW     1  ;transition occurred at inverted
                                  114                                         ;HALL input (HSI.2)
    0044                          115          VEH_SPD_OLD_TM_LO:  DSW     1  ;time at which previous positive
    0046                          116          VEH_SPD_OLD_TM_HI:  DSW     1  ;transition occurred at SPEED
```

```
ERR LOC  OBJECT                LINE        SOURCE STATEMENT
                               117                                     ;sensor input (HSI.1)
     0048                      118           RPM:                DSW     1  ;engine speed in RPM
     004A                      119           MPH:                  DSW     1    ;vehicle speed in MPH
                               120   ;
                               121   ;HSO variables
                               122   ;
                               123   PUBLIC  HSO_PERIOD_1, HSO_NEW_STAT, HSO_OLD_STAT
                               124   PUBLIC  HSO1_ON_TIME, HSO1_OFF_TIME, FMS_PW_SUM, FMS_PW_COUNT
                               125   PUBLIC  FMS_AVE_OFF_PERIOD, FMS_AVE_PW
                               126
     004C                      127           FMS_PW_SUM:         DSL     1 ;fuel mtrg sol.PW accumulator
     0050                      128           FMS_PW_COUNT:       DSW     1 ;fuel metering sol. PW update
                               129                                     ;counter
     0052                      130           FMS_AVE_PW:         DSW     1 ;average FM solenoid ON time
     0054                      131           FMS_AVE_OFF_PERIOD: DSW     1 ;average FM solenoid OFF time
     0056                      132           FMS_PW_INST:        DSW     1 ;instantaneous solenoid ON time
                               133
     0058                      134           HSO_PERIOD_1:       DSW     1 ;current HSO period
     005A                      135           HSO1_ON_TIME:       DSW     1 ;delay time before switching ON
                               136                                       ;HSO.1 & 2 (stayed low time)
     005C                      137           HSO1_OFF_TIME:      DSW     1 ;delay time before switching OFF
                               138                                     ;HSO.1 & 2 (stayed high time)
                               139   ;
                               140   ;A to D variables
                               141   ;
                               142   PUBLIC  AD_RESULT_TABLE, MAP, CALPOT, ACH2, THR_TEMP, COOL_TEMP, THR_POT
                               143   PUBLIC  ACH6, ACH7, AD_NUM
     005E                      144           AD_RESULT_TABLE:
     005E                      145                   MAP:            DSW     1
     0060                      146                   CALPOT:         DSW     1
     0062                      147                   ACH2:           DSW     1
     0064                      148                   THR_TEMP:       DSW     1
     0066                      149                   COOL_TEMP:      DSW     1
     0068                      150                   THR_POT:        DSW     1
     006A                      151                   ACH6:           DSW     1
     006C                      152                   ACH7:           DSW     1
                               153
                               154   ;
                               155   ;PW table look up variables
                               156   ;
                               157   PUBLIC  TABLE_LABEL, END_POINT, VECTOR_LABEL_L, VECTOR_LABEL_H, RPM_I_L
                               158   PUBLIC  RPM_I_H
                               159
     006E                      160           TABLE_LABEL:            DSW     1
     0070                      161           VECTOR_LABEL_L:         DSW     1
     0072                      162           VECTOR_LABEL_H:         DSW     1
     0074                      163           END_POINT:              DSW     1
                               164
     0076                      165           COOL_TEMP_PW_MULT:      DSW     1
     0078                      166           PW_MAP_RPM_BASE:        DSW     1
     007A                      167           PW_CALPOT_TRIM:         DSW     1
     007C                      168           DECEL_PW:               DSW     1
                               169
     007E                      170           RPM_I_L:                DSB     1
     007F                      171           RPM_I_H:                DSB     1
     0080                      172           MAP_PW_L:               DSB     1
     0081                      173           MAP_PW_H:               DSB     1
                               174
     0082                      175           RPM_X:                  DSB     1
     0083                      176           MAP_X:                  DSB     1
```

```
ERR LOC  OBJECT          LINE      SOURCE STATEMENT
                          177
                          178   ;
                          179   ;Software timer and IOPORT1 variables
                          180   ;
                          181   ;MODE_FLAG:
                          182   ;BIT#     7       6       5       4       3       2       1       0
                          183   ;FLAG  IDLE DEC LEANOUT DEC DUMP CT     WOT  ACC ENRICH  HSO   START/RUN
                          184   ; 0     NO        NO      NO      NO      NO       NO     DISABLED  START
                          185   ; 1     YES       YES     YES     YES     YES      YES    ENABLED    RUN
                          186   ;
                          187   PUBLIC ACCUM_MAP, AVE_MAP, MAP_COUNT
                          188
0084                      189        ACCUM_MAP:              DSW     1
0086                      190        AVE_MAP:                DSW     1  ;average MAP
0088                      191        DELTA_MAP:              DSW     1  ;MAP - AVE_MAP
                          192
008A                      193        ACC_ENRICH_DMAP:        DSW     1  ;Minimum delta MAP to trigger
                          194                                           ;enrichment
008C                      195        ACC_ENRICH_TIME:        DSW     1  ;acceleration enrichment
                          196                                           ;solenoid ON time
008E                      197        ACC_ENRICH_STOP_TIME:   DSW     1  ;Time to stop accel enrichment
                          198                                           ;in TIMER_1_HI COUNTS
0090                      199        DEC_DUMP_DMAP:          DSW     1  ;Minimum delta MAP to trigger
                          200                                           ;decel dump
0092                      201        DEC_DUMP_TIME:          DSW     1  ;decel dump solenoid ON time
0094                      202        DEC_DUMP_STOP_TIME:     DSW     1  ;Time to stop decel dump
                          203                                           ;in TIMER_1_HI COUNTS
                          204
0096                      205        AD_NUM:                 DSB     1       ;A to D channel counter
0097                      206        HSI_D_AVAIL_FLAG:       DSB     1       ;HSI data available flag
0098                      207        HSO_NEW_STAT:           DSB     1       ;HSO state flags
0099                      208        HSO_OLD_STAT:           DSB     1       ;
009A                      209        IOSO_BAK:               DSB     1       ;IOSO register image
009B                      210        IOS1_BAK:               DSB     1       ;IOS1 register image
009C                      211        MODE_FLAG:              DSB     1       ;Operation mode flag
                          212
009D                      213        MAP_COUNT:              DSB     1 ;counter for MAP accumulator
                          214   ;
                          215   ;Throttle position limits
                          216   ;
009E                      217        WOT_H:                  DSB     1  ;WOT higher limit set point
009F                      218        WOT_L:                  DSB     1  ;WOT lower limit set point
00A0                      219        CLOSED_THR_H:           DSB     1  ;CLOSED THR higher limit
00A1                      220        CLOSED_THR_L:           DSB     1  ;CLOSED THR lower limit
                          221   ;
                          222   ;Character storage and flag registers
                          223   ;
                          224   ;CHR_IO_FLAG
                          225   ;BIT    7       6       5       4       3       2       1       0
                          226   ;                               ALL    APPEND  DONE    FIRST    NEW
                          227   ;                              DONE    CHAR $  NULL   ENTRY TO COMMAND
                          228   ;                                      CHR    SEND_CHR RECVD
                          229   ;
                          230   ;SET                            YES     YES     YES     YES     YES
                          231   ;CLEAR                          NO      NO      NO      NO      NO
                          232   ;
                          233   PUBLIC CHR_IO_FLAG, RECV_CHR
                          234
00A2                      235          CHR_IO_FLAG:             DSB     1
00A3                      236          RECV_CHR:                DSB     1
                          237   ;
                          238   ;Setup Interrupt Vectors
                          239   ;
2000                      240   CSEG AT 2000H
```

```
ERR LOC  OBJECT              LINE      SOURCE STATEMENT
                              241
                              242  EXTRN   ATOD_DONE_INT   :ENTRY
                              243  EXTRN   HSI_DATA_INT    :ENTRY
                              244  EXTRN   HSO_EXEC_INT    :ENTRY
                              245  EXTRN   SW_TMR_INT      :ENTRY
                              246  EXTRN   TIMER_OVF_INT   :ENTRY
                              247
    2000 0000           E     248          DCW     TIMER_OVF_INT
    2002 0000           E     249          DCW     ATOD_DONE_INT
    2004 0000           E     250          DCW     HSI_DATA_INT
    2006 0000           E     251          DCW     HSO_EXEC_INT
    2008 0000           E     252          DCW     HSI_DATA_INT
    200A 0000           E     253          DCW     SW_TMR_INT
    200C 0000           E     254          DCW     HSI_DATA_INT
    200E 0000           E     255          DCW     HSI_DATA_INT
    2010 8020                 256          DCW     INIT_PWR_UP
                              257  ;
                              258  ;Reset/Power-up Initialization Routine
                              259  ;
    2080                      260  CSEG AT 2080H
                              261
                              262  EXTRN   HSI_UPDATE_CHECK        :ENTRY
                              263  EXTRN   DELAY                   :ENTRY
                              264  EXTRN   INIT_8256               :ENTRY
                              265  EXTRN   SEND_SIGNON_MSSG        :ENTRY
                              266  EXTRN   PROCESS_MUART_CMD       :ENTRY
                              267
    2080                      268  INIT_PWR_UP:
    2080 FA                   269     DI
    2081 A1008118             270     LD      SP, #8100H              ;setup stack pointer
    2085 EF0000         E     271     CALL    DELAY                   ;wait 500 msec for MUART to reset
    2088 EF0000         E     272     CALL    INIT_8256               ;initialize MUART registers & set
                              273                                     ;communication parameters
    2088 B103A3               274     LDB     RECV_CHR, #03           ;load a CNTRL_C into RECV_CHR and
    208E B103A2               275     LDB     CHR_IO_FLAG, #00000011B ;initialize CHR_IO_FLAG to
                              276                                     ;simulate having received a
                              277                                     ;command character from MUART
    2091 EF0000         E     278     CALL    PROCESS_MUART_CMD       ;to write the sign on message
                              279  ;
                              280  ;Clear HSI registers and MODE_FLAG
                              281  ;
    2094 0126                 282          CLR     TIMER_1_HI
    2096 0128                 283          CLR     HALF_MIN_TIMER
    2098 0140                 284          CLR     RPM_OLD_TIME_LO
    209A 0142                 285          CLR     RPM_OLD_TIME_HI
    209C 0148                 286          CLR     RPM
    209E 014A                 287          CLR     MPH
    20A0 0144                 288          CLR     VEH_SPD_OLD_TM_LO
    20A2 0146                 289          CLR     VEH_SPD_OLD_TM_HI
    20A4 1197                 290          CLRB    HSI_D_AVAIL_FLAG
    20A6 119A                 291          CLRB    IOS0_BAK
    20A8 1198                 292          CLRB    IOS1_BAK
    20AA 119C                 293          CLRB    MODE_FLAG               ;flag START mode
                              294  ;
                              295  ;Clear and setup software timer registers
                              296  ;
    20AC 1190                 297          CLRB    MAP_COUNT
    20AE 0184                 298          CLR     ACCUM_MAP
                              299
                              300  ;
                              301  ;Setup HSI and Interrupt registers
                              302  ;
    20B0 B11415               303     LDB     IOC0, #00010100B        ;enable HSI.1 & HSI.2
    20B3 B11403               304     LDB     HSI_MODE, #00010100B    ;set HSI.1 & 2 to look for positive
```

```
ERR LOC  OBJECT              LINE        SOURCE STATEMENT
                              305                                  ;going edges only
    20B6 B10416               306     LDB     IOC1, #00000100B     ;enable HSI interrupt when FIFO
                              307                                  ;is first loaded
    20B9 912F08               308     ORB     INT_MASK, #00101111B ;enable timer1 overflow, HSI, HSO
                              309                                  ;A to D complete and software
                              310                                        ;timer interrupts
    20BC FB                   311       EI                            ;global interrupt enable
                              312   ;
                              313   ;Clear HSO PW registers
                              314   ;
    20BD 014C                 315       CLR     FMS_PW_SUM   ;initialize FMS PW accumulator lower word
    20BF 014E                 316       CLR     FMS_PW_SUM+2 ;initialize FMS PW accumulator higher word
    20C1 0150                 317       CLR     FMS_PW_COUNT ;initialize FMS PW update counter
                              318   ;
                              319   ;Read analog sensor signals
                              320   ;
    20C3 28CC                 321           CALL    AD_READ                ;take analog sensor readings
    20C5 A05E86               322           LD      AVE_MAP, MAP           ;intialize AVE_MAP
    20C8 FA                   323           DI
    20C9 B11806               324           LDB     HSO_COMMAND, #00011000B  ;initialize a SWT0 interrupt
    20CC 45BE0A0A04           325           ADD     HSO_TIME, TIMER1, #0ABEH ;in 5.5ms
    20D1 FB                   326           EI
    20D2 FA                   327           DI
    20D3 B11906               328           LDB     HSO_COMMAND, #00011001B  ;initialize a SWT1 interrupt
    20D6 4524F40A04           329           ADD     HSO_TIME, TIMER1, #0F424H ;in 125ms
    20D8 FB                   330           EI
    20DC FA                   331           DI
    20DD B11A06               332           LDB     HSO_COMMAND, #00011010B  ;initialize a SWT2 interrupt
    20E0 4500010A04           333           ADD     HSO_TIME, TIMER1, #0100H ;in 0.512ms
    20E5 FB                   334           EI
                              335   ;
                              336   ;Engine Monitor Main Routine
                              337   ;
    20E6                      338   ENG_MAIN_MONITOR:
                              339
    20E6 B11E0A               340           LDB     WATCHDOG, #1EH         ;clear and start watchdog
    20E9 B1E10A               341           LDB     WATCHDOG, #0E1H        ;timer
                              342
    20EC 28C1                 343           CALL    SET_MODE
    20EE 389C4B               344           JBS     MODE_FLAG, 0, IN_RUN_MODE
                              345
    20F1                      346   IN_START_MODE:
                              347   ;
                              348   ;In START mode, calculate START pulse width for HSO driver and start HSO
                              349   ;energize accel enrichment solenoid to aid starting
                              350   ;
                              351   ;MODE_FLAG.0: START =0, RUN =1
                              352   ;MODE_FLAG.1: disable HSO =0, enable HSO =1
                              353   ;
                              354   EXTRN   HSO1_START_PERIOD       :WORD
                              355   EXTRN   HSO_PW_START_MAX        :WORD
                              356   EXTRN   HSO_PW_START_MIN        :WORD
                              357   EXTRN   STR_H_COOL_TEMP_PW_TBL  :NULL
                              358   EXTRN   STR_L_COOL_TEMP_PW_TBL  :NULL
                              359
    20F1 289E                 360    CALL    AD_READ                        ;take sensor readings
    20F3 A06624               361    LD      EX, COOL_TEMP                  ;get coolant temperature
    20F6 380F06               362    JBS     IOPORT1, 0, USE_LOW_C_TEMP_TBL ;jump if P1.0 is set,low temp
                              363                                           ;scale is in use.
    20F9 A100006E         E   364    LD      TABLE_LABEL, #STR_H_COOL_TEMP_PW_TBL ;P1.0 is cleared, cool
    20FD 2004                 365    BR      LOOK_UP_C_TEMP_PW              ;temp sensor at high temp
                              366                                           ;scale, get high temp
                              367                                           ;scale table address
    20FF                      368   USE_LOW_C_TEMP_TBL:
```

```
ERR LOC  OBJECT                LINE        SOURCE STATEMENT
    20FF A100006E          E    369    LD    TABLE_LABEL, #STR_L_COOL_TEMP_PW_TBL ;get low temp scale
                                370                                               ;table address
    2103                        371    LOOK_UP_C_TEMP_PW:
    2103 EF0000            E    372     CALL    UNSIGNED_TABLE_LK_UP    ;look up start PW
    2106 09081C                 373     SHL     AX, #8                  ;multiply resulting PW in AX by 100H
    2109 A01C3C                 374     LD      PW_FMS, AX              ;load result into PW_FMS
                                375    ;
                                376    ;Pass FMS PW parameters to HSO driver
                                377    ;
    210C A301000020        E    378       LD      CX, HSO_PW_START_MAX    ;get PW upper limit
    2111 A301000024        E    379       LD      EX, HSO_PW_START_MIN    ;get PW lower limit
    2116 A30100001C        E    380       LD      AX, HSO1_START_PERIOD   ;get RUN period for HSO1
    211B 2995                   381       CALL    CHECK_OUTPUT_HSO_PW  ;check FMS PW limits then update it
                                382
    211D 71F90F                 383       ANDB    IOPORT1, #11111001B     ;clear P1.1 and P1.2 to energize
                                384                                          ;accel solenoids for atmospheric
                                385                                           ;vent to aid starting
                                386
    2120 399C14                 387       JBS     MODE_FLAG, 1, END_START_MODE ;jump if HSO already enabled
    2123 91029C                 388       ORB     MODE_FLAG, #00000010B          ;if not then enable HSO
                                389
    2126 A0565C                 390       LD      HSO1_OFF_TIME, FMS_PW_INST    ;initialize FMS average PW
    2129 4856585A               391       SUB     HSO1_ON_TIME, HSO_PERIOD_1, FMS_PW_INST
                                392                                          ;initialize FMS average OFF period
    212D 51061599               393       ANDB    HSO_OLD_STAT, IOSO, #06H ;get current state of HSO.1 &2
    2131 950699                 394       XORB    HSO_OLD_STAT, #06H   ;invert current state of HSO.1 &2
    2134 910809                 395       ORB     INT_PENDING, #00001000B ;fake a HSO interrupt to start
                                396                                          ;HSO.1 and HSO.2
    2137                        397    END_START_MODE:
    2137 EF0000            E    398       CALL    PROCESS_MUART_CMD   ;process command received from MUART
    213A 27AA                   399       BR      ENG_MAIN_MONITOR
                                400
    213C                        401    IN_RUN_MODE:
                                402    ;
                                403    ;In RUN mode, calculate RUN pulse width for HSO driver and enable MAP
                                404    ;TRANSIENT subroutine
                                405    ;
                                406    ;MODE_FLAG.0: START =0, RUN =1
                                407    ;MODE_FLAG.1: disable HSO =0, enable HSO =1
                                408    ;
                                409    EXTRN   HSO1_RUN_PERIOD          :WORD
                                410    EXTRN   MAX_HSO_PW               :WORD
                                411    EXTRN   MIN_HSO_PW               :WORD
                                412    EXTRN   CALPOT_TRIM              :NULL
                                413
    213C 2997                   414       CALL    CHECK_THR_POT          ;update throttle control mode
    213E 29F3                   415       CALL    CHECK_IDLE             ;determine if it is at idle
    2140 288D                   416       CALL    LOOK_UP_MAP_RPM_BASE_PW     ;update MAP_RPM_BASE_PW
                                417    ;
                                418    ;Look up calibration potentiometer pulse width trim
                                419    ;
    2142 A06024                 420       LD      EX, CALPOT           ;load current CALPOT value into EX
    2145 A100006E          E    421       LD      TABLE_LABEL, #CALPOT_TRIM ;load table label
    2149 EF0000            E    422       CALL    SIGNED_TABLE_LK_UP     ;look up CALPOT pulse width trim
    214C A01C7A                 423       LD      PW_CALPOT_TRIM, AX     ;record result
                                424
    214F 2932                   425       CALL    LOOK_UP_DECEL_PW       ;look up decel leanout pulse width
    2151 2919                   426       CALL    LOOK_UP_COOL_TEMP_MULT ;look up cool. temp multiplier
                                427 ;
                                428 ;Calculate PW_FMS
                                429 ;PW_FMS = (PW_MAP_RPM_BASE + PW_CALPOT_TRIM + DECEL_PW)*
                                430 ;         (100H + COOL_TEMP_PW_MULT)
                                431 ;
                                432 ;PW_MAP_BASE=0000 to 00C3H(lower byte contains higher byte count of TIMER1)
```

```
ERR LOC  OBJECT                LINE        SOURCE STATEMENT
                               433 ;PW_CALPOT_TRIM = 0000 to 007FH (0 to +127) and FFFFH to FF80H (-1 to -128)
                               434 ;DECEL_PW = 0000 to 00FFH (0 to +255)
                               435 ;COOL_TEMP_PW_MULT = 00 to 7FH (0 to +127) and FFH to 80H (-1 to -128)
                               436 ;
                               437 ;Note: MAP and RPM based PW is trimmed (signed addition) by CALPOT and
                               438 ;decel leanout pulse width, the result is modified by cool temp mult factor
                               439 ;up to +/- 50%
                               440 ;
  2153 447A783C                441       ADD     PW_FMS, PW_MAP_RPM_BASE, PW_CALPOT_TRIM ;add CALPOT trim
  2157 647C3C                  442       ADD     PW_FMS, DECEL_PW                ;add decel leanout pw
  215A D602                    443       JGE     NON_NEGATIVE                    ;if PW is negative
  215C 013C                    444       CLR     PW_FMS                          ;then set it to zero
                               445
  215E                         446  NON_NEGATIVE:
  215E B9C3003C                447       CMP     PW_FMS, #00C3H          ;if it exceeds max. limit
  2162 DA04                    448       JLE     COOL_TEMP_CORRECTION    ;then set it to max. PW/100H
  2164 A1C3003C                449       LD      PW_FMS, #00C3H          ;
                               450
  2168                         451  COOL_TEMP_CORRECTION:
  2168 65000176                452       ADD     COOL_TEMP_PW_MULT, #100H  ;COOL_TEMP_PW_MULT + 100H
  216C 6C763C                  453       MULU    PW_FMS, COOL_TEMP_PW_MULT ;multiply PW by
                               454                                       ;(100H+cool temp factor)
  216F 88003E                  455       CMP     PW_FMS+2, ZERO          ;jump if higher word is zero
  2172 DF05                    456       JE      OUTPUT_HSO_PW         ;higher word non-zero indicating
  2174 A30100003C      E       457       LD      PW_FMS, MAX_HSO_PW    ;result exceeds 1 word wide
                               458                                     ;set it to PW upper limit
                               459  ;
                               460  ;Check FMS PW limits and then store it
                               461  ;
  2179                         462  OUTPUT_HSO_PW:
  2179 A301000020      E       463       LD      CX, MAX_HSO_PW        ;pass variables to
  217E A301000024      E       464       LD      EX, MIN_HSO_PW        ;called routine
  2183 A30100001C      E       465       LD      AX, HSO1_RUN_PERIOD   ;get RUN period for HSO
  2188 2928                    466       CALL    CHECK_OUTPUT_HSO_PW   ;check HSO_PW limits then output it
  218A 29C0                    467       CALL    MAP_TRANSIENT         ;accel/decel control
  218C EF0000          E       468       CALL    PROCESS_MUART_CMD     ;process command received from MUART
  218F 2755                    469       BR      ENG_MAIN_MONITOR
                               470
                               471  ;
                               472  ;AD_READ routine
                               473  ;
                               474  ;Read analog channels now, A to D conversion triggered by
                               475  ;HSI is bypassed.
                               476  ;AD_NUM.7=1 indicates conversion in progress, ATOD_DONE_INT clears flag
                               477  ;when conversion is complete
                               478  ;Control of ACH increment
                               479  ;AD_NUM.6 =1 indicates AD_READ in control, AD_NUM.6 =0 indicates
                               480  ;ATOD_DONE_INT in control
                               481  ;
  2191                         482  AD_READ:
  2191 1196                    483       CLRB    AD_NUM              ;set analog channel counter to 0
                               484
  2193                         485  START_AD:
  2193 91C096                  486       ORB     AD_NUM, #11000000B  ;set AD_NUM.7 to indicate A to D in
                               487                                   ;progress and AD_READ in control
  2196 55089602                488       ADDB    AD_COMMAND, AD_NUM, #1000B ;do A to D now on current ACH
                               489
  219A                         490  CONTINUE_AD:
  219A 3F96FD                  491       JBS     AD_NUM, 7, CONTINUE_AD  ;
  219D 510F9622                492       ANDB    DX, AD_NUM, #00001111B  ;get current ACH channel NO.
  21A1 990722                  493       CMPB    DX, #7                  ;has conversion reached ACH7 ?
  21A4 D604                    494       JGE     END_AD                  ;jump if yes
  21A6 1796                    495       INCB    AD_NUM                  ;if no continue with next ACH
  21A8 27E9                    496       BR      START_AD
```

```
ERR LOC  OBJECT                LINE      SOURCE STATEMENT
    21AA                        497   END_AD:
    21AA 1196                   498       CLRB    AD_NUM      ;A to D done, reset ACH counter to channel 0
                                499                                   ;pass control to ATOD_DONE_INT
    21AC 1102                   500       CLRB    AD_COMMAND      ;A to D to be triggered by HSI_INT
    21AE F0                     501       RET
                                502   ;
                                503   ;SET_MODE routine
                                504   ;
                                505   ;Determine RUN/START and START/RUN Transfer
                                506   ;MODE_FLAG.0: START =0, RUN =1
                                507   ;
                                508   EXTRN   STR_RUN_TR_RPM: WORD
                                509   EXTRN   RUN_STR_TR_RPM: WORD
                                510
    21AF                        511   SET_MODE:
    21AF EF0000          E      512       CALL    HSI_UPDATE_CHECK          ;check HSI for valid data,
                                513                                         ;update RPM and MPH
    21B2 8B01000048      E      514       CMP     RPM, STR_RUN_TR_RPM       ;jump if RPM below START to
    21B7 DA08                   515       JLE     CHECK_START_MODE          ;RUN transfer RPM
                                516
    21B9                        517   RUN_MODE:
    21B9 389C05                 518       JBS     MODE_FLAG, 0, CHECK_START_MODE ;jump if already in RUN mode
    21BC 91019C                 519       ORB     MODE_FLAG, #00000001B          ;set MODE_FLAG.0 to indicate
    21BF 2000                   520       BR      END_SET_MODE                   ;RUN mode
                                521
    21C1                        522   CHECK_START_MODE:
    21C1 309C0A                 523       JBC     MODE_FLAG, 0, END_SET_MODE ;exit if already in START mode
    21C4 8B01000048      E      524       CMP     RPM, RUN_STR_TR_RPM        ;if RPM is above RUN to START
    21C9 D603                   525       JGE     END_SET_MODE               ;transfer RPM
                                526
    21CB                        527   START_MODE:
    21CB 71FE9C                 528       ANDB    MODE_FLAG, #11111110B  ;clear MODE_FLAG.0 to indicate
                                529                                      ;START mode
    21CE                        530   END_SET_MODE:
    21CE F0                     531       RET
                                532   ;
                                533   ;LOOK_UP_MAP_RPM_BASE_PW: routine to look up MAP and RPM based PW
                                534   ;
                                535   EXTRN   RPM_PT_MAP_PW_VECTOR    :NULL
                                536   EXTRN   RPM_WOT_MAP_PW_VECTOR   :NULL
                                537   EXTRN   RPM_IDLE_MAP_PW_VECTOR  :NULL
                                538   EXTRN   UNSIGNED_TABLE_LK_UP    :ENTRY
                                539   EXTRN   SIGNED_TABLE_LK_UP      :ENTRY
                                540   EXTRN   LOCATE_MAP_PW_TABLE     :ENTRY
                                541
    21CF                        542   LOOK_UP_MAP_RPM_BASE_PW:
    21CF A04820                 543       LD      CX, RPM
    21D2 9D2020                 544       DIVUB   CX, #20H                    ;load RPM/32 into CX
    21D5 B02082                 545       LDB     RPM_X, CL                   ;load RPM/32 into RPM_X
    21D8 A05E24                 546       LD      EX, MAP                     ;read MAP into EX
                                547
    21DB 3B9C23                 548       JBS     MODE_FLAG, 3, WOT_LOOK_UP   ;bit 3 set, indicates WOT
    21DE 3F9C40                 549       JBS     MODE_FLAG, 7, IDLE_LOOK_UP  ;bit 7 set, indicates idle,
                                550                                         ;use CT_LOOK_UP, or else use
                                551                                         ;PT_LOOK_UP
    21E1                        552   PT_LOOK_UP:
    21E1 A100006E        E      553       LD    TABLE_LABEL, #RPM_PT_MAP_PW_VECTOR ;get RPM vector table
    21E5 EF0000          E      554       CALL  LOCATE_MAP_PW_TABLE     ;label, look up RPM_I_L, RPM_I_H,
                                555                                     ;VECTOR_LABEL_L and VECTOR_LABEL_H
                                556                                     ;RPM_X already in CL
    21E8 A0706E                 557       LD    TABLE_LABEL, VECTOR_LABEL_L  ;get table address, MAP already
                                558                                        ;in EX
    21EB EF0000          E      559       CALL  UNSIGNED_TABLE_LK_UP      ;look up MAP_PW_L
    21EE B01C80                 560       LDB   MAP_PW_L, AL              ;get result
```

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ERR LOC  OBJECT              LINE        SOURCE STATEMENT
                             561
    21F1 887270              562     CMP   VECTOR_LABEL_L, VECTOR_LABEL_H  ;if the same, use break point
    21F4 DF72                563     JE    USE_THIS_BREAK_PT               ;values without interpolation
                             564
    21F6 A0726E              565     LD    TABLE_LABEL, VECTOR_LABEL_H     ;get table address
    21F9 EF0000          E   566     CALL  UNSIGNED_TABLE_LK_UP            ;look up MAP_PW_H
    21FC B01C81              567     LDB   MAP_PW_H, AL                    ;get result
                             568
    21FF 203E                569     BR    CAL_RPM_MAP_BASE_PW              ;do interpolation
                             570
    2201                     571   WOT_LOOK_UP:
    2201 A100006E        E   572      LD  TABLE_LABEL, #RPM_WOT_MAP_PW_VECTOR ;get RPM vector table label
    2205 EF0000          E   573     CALL    LOCATE_MAP_PW_TABLE     ;look up RPM_I_L, RPM_I_H, VECTOR_
                             574                                     ;LABEL_L and VECTOR_LABEL_H
    2208 A0706E              575     LD  TABLE_LABEL, VECTOR_LABEL_L ;get table address, MAP already
                             576                                     ;in EX
    220B EF0000          E   577     CALL    UNSIGNED_TABLE_LK_UP            ;look up MAP_PW_L
    220E B01C80              578     LDB     MAP_PW_L, AL                    ;get result
                             579
    2211 887270              580     CMP     VECTOR_LABEL_L, VECTOR_LABEL_H ;if the same,use break point
    2214 DF52                581     JE      USE_THIS_BREAK_PT             ;values without interpolation
                             582
    2216 A0726E              583     LD      TABLE_LABEL, VECTOR_LABEL_H     ;get table address
    2219 EF0000          E   584     CALL    UNSIGNED_TABLE_LK_UP            ;look up MAP_PW_H
    221C B01C81              585     LDB     MAP_PW_H, AL                    ;get result
                             586
    221F 201E                587     BR      CAL_RPM_MAP_BASE_PW             ;do interpolation
                             588
    2221                     589   IDLE_LOOK_UP:
    2221 A100006E        E   590     LD      TABLE_LABEL, #RPM_IDLE_MAP_PW_VECTOR ;get RPM vector table
    2225 EF0000          E   591     CALL    LOCATE_MAP_PW_TABLE     ;label, look up RPM_I_L, RPM_I_H,
                             592                                     ;VECTOR_LABEL_L and VECTOR_LABEL_H
    2228 A0706E              593     LD      TABLE_LABEL, VECTOR_LABEL_L ;get table address, MAP already
                             594                                         ;in EX
    222B EF0000          E   595     CALL    UNSIGNED_TABLE_LK_UP            ;look up MAP_PW_L
    222E B01C80              596     LDB     MAP_PW_L, AL                    ;get result
                             597
    2231 887270              598     CMP     VECTOR_LABEL_L, VECTOR_LABEL_H ;if the same, use break point
    2234 DF32                599     JE      USE_THIS_BREAK_PT       ;values without interpolation
                             600
    2236 A0726E              601     LD      TABLE_LABEL, VECTOR_LABEL_H     ;get table address
    2239 EF0000          E   602     CALL    UNSIGNED_TABLE_LK_UP            ;look up MAP_PW_H
    223C B01C81              603     LDB     MAP_PW_H, AL                    ;get result
                             604 ;
                             605 ;CAL_RPM_MAP_BASE_PW routine:
                             606 ;Calculates RPM_MAP_BASE_PW using linear interpolation between break
                             607 ;points RPM_I_L and RPM_I_H
                             608 ;PW_MAP_RPM_BASE =[MAP_PW_L+(MAP_PW_H-MAP_PW_L)*(RPM_X-RPM_I_L)/
                             609 ;                   (RPM_I_H-RPM_I_L)]*100H
                             610 ;
    223F                     611   CAL_RPM_MAP_BASE_PW:
    223F 587E8220            612     SUBB    CL, RPM_X, RPM_I_L      ;calculate delta RPM
    2243 AC2020              613     LDBZE   CX, CL                  ;extend result to word wide
    2246 AC811C              614     LDBZE   AX, MAP_PW_H            ;load MAP_PW_H to AX
    2249 AC8024              615     LDBZE   EX, MAP_PW_L            ;load MAP_PW_L to EX
    224C 68241C              616     SUB     AX, EX                  ;calculate delta MAP_PW
    224F FE6C201C            617     MUL     AX, CX                  ;delta MAP_PW* delta RPM
    2253 587E7F20            618     SUBB    CL, RPM_I_H, RPM_I_L    ;calculate delta RPM break pt
    2257 DF0F                619     JE      USE_THIS_BREAK_PT       ;jump if RPM_I_H=RPM_I_L
    2259 AC2020              620     LDBZE   CX, CL                  ;extend result into word
    225C FE8C201C            621     DIV     AXL, CX          ;calculate delta MAP_PW*delta RPM/
                             622                              ;delta RPM break pt
    2260 64241C              623     ADD     AX, EX                  ;result + MAP_PW_L
    2263 A01C78              624     LD      PW_MAP_RPM_BASE, AX ;store result in MAP RPM based PW reg
```

```
ERR LOC  OBJECT              LINE        SOURCE STATEMENT
    2266 2003                625    BR      EXIT_MAP_RPM_PW_LOOKUP
                             626
    2268                     627  USE_THIS_BREAK_PT:
    2268 AC8078              628    LDBZE   PW_MAP_RPM_BASE, MAP_PW_L ;use value in MAP_PW_L
                             629
    2268                     630  EXIT_MAP_RPM_PW_LOOKUP:
    2268 F0                  631    RET
                             632
                             633    ;
                             634    ;LOOK_UP_COOL_TEMP_MULT: Routine to look up coolant temp
                             635    ;multiplication factor for HSO RUN PW
                             636    ;
                             637    EXTRN   H_COOL_TEMP_PW_MULT_TBL :NULL
                             638    EXTRN   L_COOL_TEMP_PW_MULT_TBL :NULL
                             639
    226C                     640    LOOK_UP_COOL_TEMP_MULT:
    226C A06624              641      LD      EX, COOL_TEMP                    ;get coolant temperature
    226F 380F06              642      JBS     IOPORT1, 0, LKUP_LOW_C_TEMP_TBL ;jump if P1.0 is set,
                             643                                               ;low temp scale is in used.
    2272 A100006E        E   644      LD      TABLE_LABEL, #H_COOL_TEMP_PW_MULT_TBL ;P1.0 is cleared,
    2276 2004                645      BR      LKUP_C_TEMP_PW                   ;it is on high temp scale,
                             646                                               ;get table address
    2278                     647    LKUP_LOW_C_TEMP_TBL:
    2278 A100006E        E   648      LD      TABLE_LABEL, #L_COOL_TEMP_PW_MULT_TBL ;get low temp scale
                             649                                                    ;table address
    227C                     650    LKUP_C_TEMP_PW:
    227C EF0000          E   651      CALL    SIGNED_TABLE_LK_UP      ;look up HSO PW multiplier
    227F A01C76              652      LD      COOL_TEMP_PW_MULT, AX   ;get result from AX
    2282 F0                  653      RET
                             654    ;
                             655    ;LOOK_UP_DECEL_PW: routine to look up decel leanout pulse width for HSO
                             656    ;RUN pulse width
                             657    ;DECEL_PW = 0 when decel leanout flag (MODE_FLAG.6) is cleared or MPH is
                             658    ;below DEC_VEH_SPD_L, or else DECEL_PW is looked up from DECEL_PW_TABLE
                             659    ;DEC_VEH_SPD_H and DEC_VEH_SPD_L provide a hysteresis band.
                             660    ;
                             661    ;MODE_FLAG.6 is flagged in Software timer 0 interrupt service routine
                             662    ;
                             663    EXTRN   DECEL_PW_TABLE          :NULL
                             664    EXTRN   DECEL_MAP_SW_PT_L       :WORD
                             665    EXTRN   DEC_VEH_SPD_H           :WORD
                             666    EXTRN   DEC_VEH_SPD_L           :WORD
                             667
    2283                     668    LOOK_UP_DECEL_PW:
    2283 369C29              669      JBC     MODE_FLAG, 6, NO_DECEL_LEANOUT ;no leanout if flag clears
    2286 880100004A      E   670      CMP     MPH, DEC_VEH_SPD_H          ;veh speed > high sw pt
    2288 D20C                671      JGT     LKUP_DECEL_PW_TB            ;look up DECEL_PW from table
    228D 880100004A      E   672      CMP     MPH, DEC_VEH_SPD_L          ;veh speed < lower sw pt
    2292 DE1B                673      JLT     NO_DECEL_LEANOUT            ;no decel leanout
    2294 88007C              674      CMP     DECEL_PW, ZERO              ;or else it is within veh spd
    2297 DF16                675      JE      NO_DECEL_LEANOUT            ;hysteresis band, allow leanout
                             676                                          ;only if DECEL_PW is non-zero
    2299                     677    LKUP_DECEL_PW_TB:
    2299 A301000024      E   678      LD      EX, DECEL_MAP_SW_PT_L       ;get lower MAP switch point
    229E 685E24              679      SUB     EX, MAP                     ;calculate delta MAP
    22A1 DA0C                680      JLE     NO_DECEL_LEANOUT            ;no leanout if less than or = 0
    22A3 A100006E        E   681      LD      TABLE_LABEL, #DECEL_PW_TABLE ;get table label
    22A7 EF0000          E   682      CALL    UNSIGNED_TABLE_LK_UP         ;look up decel pw from table
    22AA A01C7C              683      LD      DECEL_PW, AX                 ;get result
    22AD 2002                684      BR      EXIT_DECEL_LEANOUT           ;exit
                             685
    22AF                     686    NO_DECEL_LEANOUT:
    22AF 017C                687      CLR     DECEL_PW                   ;set DECEL_PW to zero for no
                             688                                         ;leanout
```

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ERR LOC  OBJECT                LINE      SOURCE STATEMENT
    22B1                        689   EXIT_DECEL_LEANOUT:
    22B1 F0                     690     RET
                                691   ;
                                692   ;CHECK_OUTPUT_HSO_PW:
                                693   ;Check if PW_FMS exceeds limits, if so set PW_FMS to limits, then pass
                                694   ;HSO PW to HSO driver
                                695   ;HSO period is already  in AX
                                696   ;PW Upper limit is already in CX
                                697   ;PW lower limit is already in EX
                                698   ;
    22B2                        699   CHECK_OUTPUT_HSO_PW:
                                700                                   ;check PW limits
    22B2 88203C                 701     CMP     PW_FMS, CX            ;if PW exceeds max, use max limit
    22B5 D105                   702     JNH     CHECK_LOW_LIMIT       ;if not check min limit
    22B7 A0203C                 703     LD      PW_FMS, CX            ;use upper limit
    22BA 2008                   704     BR      UPDATE_FMS_PW         ;
                                705
    22BC                        706   CHECK_LOW_LIMIT:
    22BC 88243C                 707      CMP     PW_FMS, EX       ;if PW below min limit, use min limit
    22BF D903                   708      JH      UPDATE_FMS_PW          ;if not use calculated PW
    22C1 A0243C                 709      LD      PW_FMS, EX             ;use lower limit
                                710   ;
                                711   ;update instantaneous FMS PW
                                712   ;update current HSO1 period which is already in AX
                                713   ;update FMS pulse width (HSO off time) accumulator and counter
                                714   ;
    22C4                        715   UPDATE_FMS_PW:
    22C4 A03C56                 716       LD   FMS_PW_INST, PW_FMS  ;update instantaneous solenoid ON time
    22C7 FA                     717       DI
    22C8 A01C58                 718       LD      HSO_PERIOD_1, AX        ;get current HSO.1 period, add
    22CB 64564C                 719       ADD     FMS_PW_SUM, FMS_PW_INST ;instant. FMS PW to accumulator
    22CE A4004E                 720       ADDC    FMS_PW_SUM+2, ZERO      ;add carry to accumulator higher
    22D1 0750                   721       INC     FMS_PW_COUNT            ;word and increment PW counter
    22D3 FB                     722       EI
    22D4 F0                     723       RET
                                724
                                725   ;
                                726   ;CHECK_THR_POT: Routine for determining throttle opening by checking
                                727   ;               the throttle position sensor reading
                                728   ;WOT and CT higher and lower limits are functions of RPM/32
                                729   ;limits are determined from corresponding tables values before being
                                730   ;used to set throttle condition
                                731   ;
                                732   ;MODE_FLAG: BIT 3: SET = WOT, CLEAR = NOT WOT
                                733   ;          BIT 4: SET = CT,  CLEAR = NOT CT
                                734   ;          BITS 3 & 4 cleared = PT
                                735   ;
                                736   EXTRN   WOT_H_TBL       :NULL
                                737   EXTRN   WOT_L_TBL       :NULL
                                738   EXTRN   CL_THR_H_TBL    :NULL
                                739   EXTRN   CL_THR_L_TBL    :NULL
                                740
    22D5                        741   CHECK_THR_POT:
    22D5 A04A24                 742     LD      EX, MPH               ;get vehicle speed MPH
    22D8 A100006E          E    743     LD      TABLE_LABEL, #CL_THR_L_TBL  ;obtain table address
    22DC EF0000            E    744     CALL    UNSIGNED_TABLE_LK_UP        ;look up CT_THR lower limit
    22DF B01CA1                 745     LDB     CLOSED_THR_L, AL      ;obtain and update result
                                746
    22E2 A100006E          E    747     LD      TABLE_LABEL, #CL_THR_H_TBL  ;obtain table address
    22E6 EF0000            E    748     CALL    UNSIGNED_TABLE_LK_UP        ;look up CT_THR higher limit
    22E9 B01CA0                 749     LDB     CLOSED_THR_H, AL      ;obtain and update result
                                750
    22EC A100006E          E    751     LD      TABLE_LABEL, #WOT_H_TBL ;obtain table address
    22F0 EF0000            E    752     CALL    UNSIGNED_TABLE_LK_UP    ;look up WOT higher limit
```

```
ERR LOC  OBJECT                LINE      SOURCE STATEMENT
    22F3 B01C9E                 753    LDB     WOT_H, AL               ;obtain and update result
                                754
    22F6 A1000006E          E   755    LD      TABLE_LABEL, #WOT_L_TBL ;obtain table address
    22FA EF0000             E   756    CALL    UNSIGNED_TABLE_LK_UP    ;look up WOT lower limit
    22FD B01C9F                 757    LDB     WOT_L, AL               ;obtain and update result
                                758
    2300 989E68                 759    CMPB THR_POT, WOT_H      ;check throttle position
    2303 D900                   760    JH   FLAG_WOT            ;if higher than WOT_H, flag WOT
    2305 989F68                 761    CMPB THR_POT, WOT_L      ;if lower than WOT_L, check CT, or
    2308 D110                   762    JNH  CHECK_CLOSED_THR    ;else it's within the hysteresis band
    230A 3B9C25                 763    JBS  MODE_FLAG, 3, EXIT_CHECK_THR  ;WOT flag has been set, no change
    230D 3C9C17                 764    JBS  MODE_FLAG, 4, FLAG_PT   ;CT bit is set, clear it to flag PT
    2310 2020                   765    BR   EXIT_CHECK_THR          ;PT has already been flagged, return
                                766
    2312                        767   FLAG_WOT:
    2312 71EF9C                 768    ANDB    MODE_FLAG, #11101111B   ;WOT, clear bit 4 and
    2315 91089C                 769    ORB     MODE_FLAG, #00001000B   ;set bit 3
    2318 2018                   770    BR      EXIT_CHECK_THR
                                771
    231A                        772   CHECK_CLOSED_THR:
    231A 98A068                 773    CMPB    THR_POT, CLOSED_THR_H   ;if higher than CT_H, indicate PT,
    231D D908                   774    JH      FLAG_PT                 ;or else check and see if it is lower
    231F 98A168                 775    CMPB    THR_POT, CLOSED_THR_L   ;than CT_L. If not, then Flag Closed
    2322 D108                   776    JNH     FLAG_CT                 ;Thr, or else it's in the hysteresis
    2324 3C9C05                 777    JBS     MODE_FLAG, 4, FLAG_CT   ;band, CT flag set, no change
                                778                                            ;or else flag PT
    2327                        779   FLAG_PT:
    2327 71E79C                 780    ANDB    MODE_FLAG, #11100111B ;clears bits 3 & 4 to indicate PT
    232A 2006                   781    BR      EXIT_CHECK_THR
    232C                        782   FLAG_CT:
    232C 71F79C                 783    ANDB    MODE_FLAG, #11110111B   ;CT, clear bit 3 and
    232F 91109C                 784    ORB     MODE_FLAG, #00010000B   ;set bit 4
                                785
    2332                        786   EXIT_CHECK_THR:
    2332 F0                     787    RET
                                788
    2333                        789   CHECK_IDLE:
                                790    ;
                                791    ;CHECK_IDLE: routine for identifying an idle condition, engine is
                                792    ;considered to be at idle if throttle is closed and vehicle speed
                                793    ;is below IDLE_MPH.
                                794   EXTRN   IDLE_MPH        :WORD
                                795
    2333 3B9C12                 796    JBS     MODE_FLAG, 3, CLEAR_IDLE_FLAG  ;bit 3 set, indicates WOT
    2336 349C0F                 797    JBC     MODE_FLAG, 4, CLEAR_IDLE_FLAG  ;bit 4 clear, indicates PT
    2339 A04A24                 798    LD      EX, MPH                        ;C.T., check vehicle speed
    233C 8801000024         E   799    CMP     EX, IDLE_MPH                   ;if veh speed greater than
    2341 D605                   800    JGE     CLEAR_IDLE_FLAG                ;or equal to IDLE_MPH,
                                801                                           ;engine is off idle
    2343                        802   SET_IDLE_FLAG:
    2343 91809C                 803    ORB     MODE_FLAG, #10000000B   ;or else set bit 7 to indicate idle
    2346 2003                   804    BR      END_IDLE_CHECK
                                805
    2348                        806   CLEAR_IDLE_FLAG:
    2348 717F9C                 807    ANDB    MODE_FLAG, #01111111B   ;clear bit 7 to indicate off idle
                                808
    2348                        809   END_IDLE_CHECK:
    2348 F0                     810    RET
                                811
    234C                        812   MAP_TRANSIENT:
                                813    ;
                                814    ;MAP_TRANSIENT: routine for updating delta MAP and determining accel or
                                815    ;             decel conditions, and execute dump solenoids (atmospheric
                                816    ;               vent) control
```

```
ERR LOC  OBJECT                LINE       SOURCE STATEMENT
                                817  ;DELTA_MAP: 0000 to 00FF positive, FFFF to FF01 negative (-1 to -FF)
                                818  ;
                                819  ;When delta MAP exceeds preset limit for accel, the accel enrichment
                                820  ;solenoids connected to P1.1 and P1.2 are energized.  When delta MAP
                                821  ;exceeds preset limit for decel, the decel lean-out solenoids connected
                                822  ;to P1.3 and P1.4 are energized. No decel dump is allowered for MPH
                                823  ;below NO_DEC_DUMP_MPH.
                                824  ;
                                825  EXTRN   DECEL_DMAP_TABLE         :NULL
                                826  EXTRN   DECEL_DUMP_TIME_TABLE    :NULL
                                827  EXTRN   NO_DEC_DUMP_MPH          :WORD
                                828  EXTRN   ACC_DMAP_TABLE           :NULL
                                829  EXTRN   ACC_ENRICH_TIME_TABLE    :NULL
                                830  EXTRN   LOOK_UP_DUMP_TIME_TB     :ENTRY
                                831
 234C 48865E88                  832    SUB     DELTA_MAP, MAP, AVE_MAP ;delta MAP = MAP - AVE_MAP
 2350 880088                    833    CMP     DELTA_MAP, ZERO         ;accel if delta MAP is positive
 2353 DE41                      834    JLT     DECEL_MODE              ;decel if it is negative
                                835
 2355                           836  ACCEL_MODE:
 2355 A04A24                    837    LD      EX, MPH                       ;get current vehicle speed
 2358 A100006E          E       838    LD      TABLE_LABEL, #ACC_DMAP_TABLE ;get enrich trigger delta MAP
                                839                                          ;table address
 235C EF0000            E       840    CALL    UNSIGNED_TABLE_LK_UP          ;look up enrich trigger DMAP
 235F A01C8A                    841    LD      ACC_ENRICH_DMAP, AX           ;get result
                                842
 2362 888A88                    843    CMP     DELTA_MAP, ACC_ENRICH_DMAP  ;if delta MAP is greater than
 2365 DA24                      844    JLE     NO_ACCEL_ENRICH             ;or equal to preset DMAP then
                                845                                        ;permit accel. enrichment
 2367                           846  ACCEL_ENRICH:
 2367 A04A20                    847    LD      CX, MPH                   ;get current vehicle speed
 236A A100006E          E       848    LD      TABLE_LABEL, #ACC_ENRICH_TIME_TABLE ;get enrich time table
                                849                                              ;address
 236E EF0000            E       850    CALL    LOOK_UP_DUMP_TIME_TB        ;look up enrich time
 2371 A01C8C                    851    LD      ACC_ENRICH_TIME, AX         ;get result
                                852
 2374 91049C                    853    ORB     MODE_FLAG, #00000100B      ;set bit 2 to flag acc enrich.
 2377 448C288E                  854    ADD     ACC_ENRICH_STOP_TIME, HALF_MIN_TIMER, ACC_ENRICH_TIME
                                855                                          ;calculate enrich time in
                                856                                          ;HALF_MIN_TIMER counts
 237B                           857  CHECK_ACC_ENRICH:
 237B 888E28                    858    CMP   HALF_MIN_TIMER, ACC_ENRICH_STOP_TIME ;jump if enrichment
 237E D208                      859    JGT     FLAG_END_OF_ACC_ENRICH   ;time is up, or else,
 2380 71F90F                    860    ANDB    IOPORT1, #11111001B      ;clear P1.1 & 2 to energize
                                861                                     ;enrichment solenoids
 2383 91180F                    862    ORB     IOPORT1, #00011000B      ;set P1.3 & P1.4 to make sure decel
                                863                                     ;solenoids are de-energized
 2386 205C                      864    BR      EXIT_MAP_TRANS           ;exit
                                865
 2388                           866  FLAG_END_OF_ACC_ENRICH:
 2388 71FB9C                    867    ANDB    MODE_FLAG, #11111011B   ;time is up, clear bit 2 to flag end
                                868                                    ;of accel enrichment
 238B                           869  NO_ACCEL_ENRICH:
 238B 3A9CED                    870    JBS     MODE_FLAG, 2, CHECK_ACC_ENRICH  ;jump if accel enrich
                                871                                           ;is still in progress
 238E 3D9C40                    872    JBS     MODE_FLAG, 5, CHECK_DEC_DUMP    ;jump if dec dump is still
                                873                                           ;in progress
 2391 911E0F                    874    ORB     IOPORT1, #00011110B     ;set P1.1, 2, 3 & 4 to de-energize
                                875                                    ;accel and decel solenoids
 2394 204E                      876    BR      EXIT_MAP_TRANS
                                877
 2396                           878  DECEL_MODE:
 2396 8B0100004A        E       879    CMP     MPH, NO_DEC_DUMP_MPH    ;if MPH is below NO_DEC_DUMP_MPH,
 2398 DA12                      880    JLE     CHECK_DUMP              ;do not allow decel dump
```

```
ERR LOC  OBJECT              LINE        SOURCE STATEMENT
                             881
    239D A04A24              882    LD      EX, MPH                  ;get current vehicle speed
    23A0 A100006E        E   883    LD      TABLE_LABEL, #DECEL_DMAP_TABLE ;get decel delta MAP table
                             884                                           ;address
    23A4 EF0000          E   885    CALL    SIGNED_TABLE_LK_UP       ;look up decel DMAP
    23A7 A01C90              886    LD      DEC_DUMP_DMAP, AX        ;get result
                             887
    23AA 889088              888    CMP     DELTA_MAP, DEC_DUMP_DMAP ;if abs delta MAP is greater than
    23AD DA08                889    JLE     DECEL_CONTROL       ;preset DMAP, then go to decel control
                             890
    23AF                     891  CHECK_DUMP:
    23AF 3A9CC9              892    JBS     MODE_FLAG, 2, CHECK_ACC_ENRICH  ;accel enrich in progress,
                             893                                           ;check stop time
    23B2 3D9C1C              894    JBS     MODE_FLAG, 5, CHECK_DEC_DUMP ;decel dump in progress, check
                             895                                         ;stop time
    23B5 202D                896    BR      EXIT_MAP_TRANS
                             897
    23B7                     898  DECEL_CONTROL:
    23B7 71FB9C              899    ANDB    MODE_FLAG, #11111011B   ;clear bit 2 to flag no accel enrich
    23BA 3D9C14              900    JBS     MODE_FLAG, 5, CHECK_DEC_DUMP ;not first entry if bit 5 is set
    23BD 91209C              901    ORB     MODE_FLAG, #00100000B   ;flag first entry to decel. control
                             902
    23C0 A04A20              903    LD      CX, MPH                  ;get current vehicle speed
    23C3 A100006E        E   904    LD      TABLE_LABEL, #DECEL_DUMP_TIME_TABLE ;get decel dump ON time
                             905                                           ;table address
    23C7 EF0000          E   906    CALL    LOOK_UP_DUMP_TIME_TB     ;look up decel dump ON time
    23CA A01C92              907    LD      DEC_DUMP_TIME, AX        ;get result
                             908
    23CD 44922894            909    ADD     DEC_DUMP_STOP_TIME, HALF_MIN_TIMER, DEC_DUMP_TIME ;calculate
                             910                                         ;decel dump time in timer_1_hi counts
    23D1                     911  CHECK_DEC_DUMP:
    23D1 889428              912    CMP     HALF_MIN_TIMER, DEC_DUMP_STOP_TIME ;jump if decel time is up
    23D4 D208                913    JGT     FLAG_END_OF_DEC_DUMP            ;or else,
    23D6 71E70F              914    ANDB    IOPORT1, #11100111B             ;clear P1.3 & 4 to energize
                             915                                            ;decel dump solenoids
    23D9 91060F              916    ORB     IOPORT1, #00000110B             ;set P1.1 & 2 to make sure
                             917                                            ;accel solenoids are
                             918                                            ;de-energized
    23DC 2006                919    BR      EXIT_MAP_TRANS                  ;exit
                             920
    23DE                     921  FLAG_END_OF_DEC_DUMP:
    23DE 71DF9C              922    ANDB    MODE_FLAG, #11011111B           ;time is up, clear bit 5 to
                             923                                            ;flag end of decel dump
    23E1 91180F              924    ORB     IOPORT1, #00011000B             ;set P1.3 & 4 to de-energize
                             925                                            ;decel dump solenoids
    23E4                     926  EXIT_MAP_TRANS:
    23E4 F0                  927    RET
                             928
    23E5                     929    END

ASSEMBLY COMPLETED,   NO ERROR(S) FOUND.
```

```
SOURCE FILE: A:CALIB_TB.INC
OBJECT FILE: A:CALIB_TB.OBJ
ERR LOC  OBJECT                LINE        SOURCE STATEMENT
                                 1   $TITLE("CALIB_TB.INC - CALIBRATION TABLES FOR FMC")
                                 2   CALIB_TB        MODULE
                                 3   ;*****************************************************************
                                 4   ;
                                 5   ;CALIB_TB.INC - CALIBRATION TABLES FOR FX-97 BASED PROPANE FUEL
                                 6   ;               METERING
                                 7   ;               CONTROLLER
                                 8   ;
                                 9   ;*****************************************************************
                                10   PUBLIC STR_RUN_TR_RPM, RUN_STR_TR_RPM
                                11   PUBLIC WOT_H_TBL, WOT_L_TBL, CL_THR_H_TBL, CL_THR_L_TBL
                                12   PUBLIC ACC_DMAP_TABLE, ACC_ENRICH_TIME_TABLE
                                13   PUBLIC DECEL_DMAP_TABLE, DECEL_DUMP_TIME_TABLE
                                14   PUBLIC HSO1_START_PERIOD, HSO1_RUN_PERIOD, RPM_PT_MAP_PW_VECTOR
                                15   PUBLIC RPM_WOT_MAP_PW_VECTOR, RPM_IDLE_MAP_PW_VECTOR
                                16   PUBLIC MAX_HSO_PW, MIN_HSO_PW, HSO_PW_START_MAX, HSO_PW_START_MIN
                                17   PUBLIC CALPOT_TRIM
                                18   PUBLIC COOL_TEMP_SCALE_SP_H, COOL_TEMP_SCALE_SP_L
                                19   PUBLIC STR_H_COOL_TEMP_PW_TBL, STR_L_COOL_TEMP_PW_TBL
                                20   PUBLIC H_COOL_TEMP_PW_MULT_TBL, L_COOL_TEMP_PW_MULT_TBL
                                21   PUBLIC DECEL_MAP_SW_PT_L, DECEL_MAP_SW_PT_H, DECEL_PW_TABLE
                                22   PUBLIC DEC_VEH_SPD_H, DEC_VEH_SPD_L, NO_DEC_DUMP_MPH, IDLE_MPH
                                23
0000                            24   CSEG
                                25   ;
                                26   ;START/RUN, RUN/START transfer RPM
                                27   ;
0000 5802                       28   STR_RUN_TR_RPM:          DCW  0258H          ;600 rpm
0002 2C01                       29   RUN_STR_TR_RPM:          DCW  012CH          ;300 rpm
                                30   ;
                                31   ;HSO.1 period and pulse width in START and RUN modes
                                32   ;
0004 50C3                       33   HSO1_START_PERIOD:       DCW  0C350H ;10 Hz, 2 micro-sec per count
0006 00C3                       34   HSO_PW_START_MAX:        DCW  0C300H ;upper limit for start HSO PW
0008 5000                       35   HSO_PW_START_MIN:        DCW  0050H  ;lower limit for start HSO PW
000A 50C3                       36   HSO1_RUN_PERIOD:         DCW  0C350H ;10 Hz, 2 micro-sec per count
000C 00C3                       37   MAX_HSO_PW:              DCW  0C300H ;maximum HSO.1 PW 99.84 ms
000E 5000                       38   MIN_HSO_PW:              DCW  0050H  ;minimum HSO.1 PW 0.16 ms
                                39   ;
                                40   ;Coolant temperature sensor scaling range switch points
                                41   ;
0010 4000                       42   COOL_TEMP_SCALE_SP_H:    DCW  0040H  ;switch pt for high temp scale
0012 DC00                       43   COOL_TEMP_SCALE_SP_L:    DCW  00DCH  ;switch pt for low temp scale
                                44   ;
                                45   ;Acceleration enrichment and decel and idle control calibrations
                                46   ;
0014 1900                       47   NO_DEC_DUMP_MPH:  DCW  0019H ;no decel dump below this speed,25mph
0016 0600                       48   IDLE_MPH:         DCW  0006H ;idle if C.T. and veh is below this
                                49                              ;speed, 6 mph
                                50   ;
                                51   ;ACC_DMAP_TABLE: DMAP to trigger Acceleration enrichment
                                52   ;                DMAP vs. MPH table
                                53   ;                      NNNN = No. of break points
                                54   ;                             Xi = vehicle speed in MPH
                                55   ;                                  Yi = delta MAP in mm Hg
                                56   ;                                       SSSi= slope
0018 0400                       57   ACC_DMAP_TABLE: DCW     0004H                ;MPH    mm Hg
001A 1416                       58                   DCB     14H, 16H             ;20,    89.1
001C 3300                       59                   DCW                  0033H
001E 1917                       60                   DCB     19H, 17H             ;25,    71.0
0020 3300                       61                   DCW                  0033H
0022 2319                       62                   DCB     23H, 19H             ;35,    77.2
0024 9D00                       63                   DCW                  009DH
0026 3021                       64                   DCB     30H, 21H             ;48,    101.9
                                65   ;
                                66   ;ACC_ENRICH_TIME_TABLE: accel enrichment solenoind ON time in
```

```
ERR LOC  OBJECT                LINE        SOURCE STATEMENT
                                 67  ;             HALF_MIN_TIMER counts, 0.000512 second/count
                                 68  ;             lower byte of HALF_MIN_TIMER=higher byte of TIMER1
                                 69  ;             higher byte of HALF_MIN_TIMER=lower byte of TIMER_1_HI
                                 70  ;                     HALF_MIN_TIMER counts vs. MPH table
                                 71  ;                     NNNN = No. of break points
                                 72  ;                             Xi = vehicle speed in mph
                                 73  ;                                     YYi = HALF_MIN_TIMER counts
                                 74  ;
     0028 0300                   75  ACC_ENRICH_TIME_TABLE:  DCW     0003H                   ;MPH    second
     002A 1400                   76                          DCB     14H, 00H                ;20
     002C 2700                   77                          DCW                 0027H       ;       0.02
     002E 1900                   78                          DCB     19H, 00H                ;25
     0030 1300                   79                          DCW                 0013H       ;       0.01
     0032 2300                   80                          DCB     23H, 00H                ;35
     0034 1300                   81                          DCW                 0013H       ;       0.01
                                 82  ;
                                 83  ;DECEL_DMAP_TABLE: DMAP to trigger decel dump
                                 84  ;                  delta MAP vs. vehicle speed table
                                 85  ;                       NNNN = No. of break points
                                 86  ;                       Xi = vehicle speed in mph
                                 87  ;                             Yi = delta MAP counts (signed value:
                                 88  ;                                     00-7FH = 00 to + 127
                                 89  ;                                     FFH-80H = -1 to - 128)
                                 90  ;                                     SSSi = SLOPE
                                 91  ;
     0036 0400                   92  DECEL_DMAP_TABLE:       DCW     0004H                   ;MPH    mm Hg
     0038 14DD                   93                          DCB     14H, 0DDH               ;20     -110
     003A 3301                   94                          DCW                 0133H
     003C 19E3                   95                          DCB     19H, 0E3H               ;25     -90
     003E 0001                   96                          DCW                 0100H
     0040 23ED                   97                          DCB     23H, 0EDH               ;35     -60
     0042 6600                   98                          DCW                 0066H
     0044 28EF                   99                          DCB     28H, 0EFH               ;40     -55
                                100  ;
                                101  ;DECEL_DUMP_TIME_TABLE: decel dump ON time in
                                102  ;                  HALF_MIN_TIMER counts, 0.000512 second/count
                                103  ;                  lower byte of HALF_MIN_TIMER=higher byte of TIMER1
                                104  ;                  higher byte of HALF_MIN_TIMER=lower byte of TIMER_1_HI
                                105  ;                         HALF_MIN_TIMER counts vs. MPH table
                                106  ;                         NNNN = No. of break points
                                107  ;                                 XXi = vehicle speed in mph (word wide)
                                108  ;                                         YYi = HALF_MIN_TIMER counts
                                109  ;
     0046 0400                  110  DECEL_DUMP_TIME_TABLE:  DCW     0004H                   ;mph    second
     0048 1900                  111                          DCB     19H, 00H                ;25
     004A 1300                  112                          DCW                 0013H       ;       0.01
     004C 1E00                  113                          DCB     1EH, 00H                ;30
     004E 6100                  114                          DCW                 0061H       ;       0.05
     0050 2300                  115                          DCB     23H, 00H                ;35
     0052 C300                  116                          DCW                 00C3H       ;       0.10
     0054 2D00                  117                          DCB     2DH, 00H                ;45
     0056 8601                  118                          DCW                 0186H       ;       0.20
                                119  ;
                                120  ;Deceleration leanout control calibrations
                                121  ;
     0058 3A00                  122  DECEL_MAP_SW_PT_L:      DCW     003AH   ;lower MAP sw pt, 19.5" Hg Vac
     005A 3C00                  123  DECEL_MAP_SW_PT_H:      DCW     003CH   ;high MAP sw pt, 19.25" Hg Vac
     005C 1300                  124  DEC_VEH_SPD_L:          DCW     0013H   ;lower veh speed sw pt 19 mph
     005E 1500                  125  DEC_VEH_SPD_H:          DCW     0015H   ;higher veh speed sw pt 21 mph
                                126  ;
                                127  ;Throttle position sensor calibrations
                                128  ;Note: Max TPS = 3.4V, Min TPS = 1.0V, WOT = 2.20V
                                129  ;                             NNNN  = NO. OF BREAK POINTS
                                130  ;                             MPH, THR VOLT
                                131  ;                                             SSSi = SLOPE
     0060 0400                  132  WOT_H_TBL:              DCW     0004H               ;WOT higher limit
     0062 1470                  133                          DCB     14H, 70H              ;20 mph, 2.196V
     0064 B301                  134                          DCW                 01B3H
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ERR LOC  OBJECT          LINE        SOURCE STATEMENT
    0066 1E81             135                        DCB     1EH, 81H            ;30 mph, 2.529V
    0068 0000             136                        DCW                 0000H
    006A 4181             137                        DCB     41H, 81H            ;65 mph, 2.529V
    006C 00FE             138                        DCW                 0FE00H
    006E 4677             139                        DCB     46H, 77H            ;70 mph, 2.333V
                          140
    0070 0400             141   WOT_L_TBL:           DCW     0004H               ;WOT lower limit
    0072 146E             142                        DCB     14H, 6EH            ;20 mph 2.157V
    0074 B301             143                        DCW                 01B3H
    0076 1E7F             144                        DCB     1EH, 7FH            ;30 mph 2.490V
    0078 0000             145                        DCW                 0000H
    007A 417F             146                        DCB     41H, 7FH            ;65 mph 2.490V
    007C 00FE             147                        DCW                 0FE00H
    007E 4675             148                        DCB     46H, 75H            ;70 mph 2.294V
                          149
    0080 0300             150   CL_THR_H_TBL:        DCW     0003H               ;CT higher limit
    0082 0E3F             151                        DCB     0EH, 3FH            ;14 mph 1.235V
    0084 56FF             152                        DCW                 0FF56H
    0086 143B             153                        DCB     14H, 3BH            ;20 mph 1.157V
    0088 3300             154                        DCW                 0033H
    008A 1E3D             155                        DCB     1EH, 3DH            ;30 mph 1.196V
                          156
    008C 0300             157   CL_THR_L_TBL:        DCW     0003H               ;CT lower limit
    008E 0E3D             158                        DCB     0EH, 3DH            ;14 mph 1.196V
    0090 56FF             159                        DCW                 0FF56H
    0092 1439             160                        DCB     14H, 39H            ;20 mph 1.118V
    0094 3300             161                        DCW                 0033H
    0096 1E3B             162                        DCB     1EH, 3BH            ;30 mph 1.156V
                          163   ;
                          164   ;Start Mode pulse width calibration table, first word indicates no. of
                          165   ;break points
                          166   ;Cool_temp HEX count is in low temp scaling range,i.e.,with 10K pullup
                          167   ;(1K pullup switched out by P1.0) = F8H to 33H (-40 C to 60 C)
                          168   ;Yi = (HSO.1 pulse width)/100H, unsigned positive short integer
                          169   ;SSSi = slope X 100H
                          170   ;                                 NNNN
                          171   ;                                 COOL_TEMP,  Yi
                          172   ;                                             SSSi
    0098 0500             173   STR_L_COOL_TEMP_PW_TBL: DCW     0005H
    009A 3002             174                        DCB     30H, 02H            ;59 C
    009C 0000             175                        DCW                 0000H
    009E 6002             176                        DCB     60H, 02H            ;51 C
    00A0 0000             177                        DCW                 0000H
    00A2 9A02             178                        DCB     9AH, 02H            ;15 C
    00A4 0000             179                        DCW                 0000H
    00A6 D802             180                        DCB     0D8H, 02H           ;-10C
    00A8 0000             181                        DCW                 0000H
    00AA F002             182                        DCB     0F0H, 02H           ;-31C
                          183   ;
                          184   ;Start Mode pulse width calibration table, first word indicates no. of
                          185   ;break points
                          186   ;Cool_temp HEX count is in high temp scaling range, i.e., with 1K pullup
                          187   ;(1K pullup switched in by P1.0) = E5H to 4DH (30 C to 120 C)
                          188   ;Yi = (HSO.1 pulse width)/100H, unsigned positive short integer
                          189   ;SSSi = slope X 100H
                          190   ;                                 NNNN
                          191   ;                                 COOL_TEMP,  Yi
                          192   ;                                             SSSi
    00AC 0500             193   STR_H_COOL_TEMP_PW_TBL: DCW     0005H
    00AE 5C02             194                        DCB     5CH, 02H            ;110 C
    00B0 0000             195                        DCW                 0000H
    00B2 6D02             196                        DCB     6DH, 02H            ;110 C
    00B4 0000             197                        DCW                 0000H
    00B6 9402             198                        DCB     94H, 02H            ;80 C
    00B8 0000             199                        DCW                 0000H
    00BA A802             200                        DCB     0A8H, 02H           ;70 C
    00BC 0000             201                        DCW                 0000H
    00BE E502             202                        DCB     0E5H, 02H           ;30 C
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ERR LOC  OBJECT                LINE      SOURCE STATEMENT
                               203
                               204   ;
                               205   ;PART THROTTLE RPM based MAP_PW vector table
                               206   ;First word indicates no. of break points
                               207   ;                                  NNNN
                               208   ;                                  RPM/32, MAP base PW table vector
                               209   ;
   00C0 0D00                   210   RPM_PT_MAP_PW_VECTOR:  DCW    0D00H
   00C2 1000                   211                          DCB    10H, 00H                  ;512
   00C4 2A01             R     212                          DCW        PT_MAP_PW_1
   00C6 1900                   213                          DCB    19H, 00H                  ;800
   00C8 3601             R     214                          DCW        PT_MAP_PW_2
   00CA 1F00                   215                          DCB    1FH, 00H                  ;992
   00CC 4401             R     216                          DCW        PT_MAP_PW_3
   00CE 2500                   217                          DCB    25H, 00H                  ;1184
   00D0 5001             R     218                          DCW        PT_MAP_PW_4
   00D2 2C00                   219                          DCB    2CH, 00H                  ;1408
   00D4 B001             R     220                          DCW        PT_MAP_PW_5
   00D6 3200                   221                          DCB    32H, 00H                  ;1600
   00D8 B001             R     222                          DCW        PT_MAP_PW_6
   00DA 3800                   223                          DCB    38H, 00H                  ;1792
   00DC D801             R     224                          DCW        PT_MAP_PW_7
   00DE 3E00                   225                          DCB    3EH, 00H                  ;1984
   00E0 0402             R     226                          DCW        PT_MAP_PW_8
   00E2 4500                   227                          DCB    45H, 00H                  ;2208
   00E4 3002             R     228                          DCW        PT_MAP_PW_9
   00E6 4B00                   229                          DCB    4BH, 00H                  ;2400
   00E8 5C02             R     230                          DCW        PT_MAP_PW_10
   00EA 5700                   231                          DCB    57H, 00H                  ;2784
   00EC B802             R     232                          DCW        PT_MAP_PW_11
   00EE 6400                   233                          DCB    64H, 00H                  ;3200
   00F0 AC02             R     234                          DCW        PT_MAP_PW_12
   00F2 7000                   235                          DCB    70H, 00H                  ;3584
   00F4 D002             R     236                          DCW        PT_MAP_PW_13
                               237   ;
                               238   ;WOT RPM based MAP_PW vector table
                               239   ;First word indicates no. of break points
                               240   ;                                  NNNN
                               241   ;                                  RPM/32, MAP base PW table vector
                               242   ;
   00F6 0300                   243   RPM_WOT_MAP_PW_VECTOR:  DCW    0003H
   00F8 1F00                   244                          DCB    1FH, 00H                  ;992
   00FA F002             R     245                          DCW        WOT_MAP_PW_1
   00FC 2C00                   246                          DCB    2CH, 00H                  ;1408
   00FE FC02             R     247                          DCW        WOT_MAP_PW_2
   0100 3F00                   248                          DCB    3FH, 00H                  ;2016
   0102 0C03             R     249                          DCW        WOT_MAP_PW_3
                               250   ;
                               251   ;CT RPM based MAP_PW vector table
                               252   ;First word indicates no. of break points
                               253   ;                                  NNNN
                               254   ;                                  RPM/32, MAP base PW table vector
                               255   ;
   0104 0900                   256   RPM_IDLE_MAP_PW_VECTOR: DCW    0009H
   0106 1000                   257                          DCB    10H, 00H                  ;512
   0108 1C03             R     258                          DCW        IDLE_MAP_PW_1
   010A 1900                   259                          DCB    19H, 00H                  ;800
   010C 2403             R     260                          DCW        IDLE_MAP_PW_2
   010E 1F00                   261                          DCB    1FH, 00H                  ;992
   0110 3403             R     262                          DCW        IDLE_MAP_PW_3
   0112 2500                   263                          DCB    25H, 00H                  ;1184
   0114 3C03             R     264                          DCW        IDLE_MAP_PW_4
   0116 2C00                   265                          DCB    2CH, 00H                  ;1408
   0118 4403             R     266                          DCW        IDLE_MAP_PW_5
   011A 3200                   267                          DCB    32H, 00H                  ;1600
   011C 4C03             R     268                          DCW        IDLE_MAP_PW_6
   011E 3E00                   269                          DCB    3EH, 00H                  ;1984
   0120 5403             R     270                          DCW        IDLE_MAP_PW_7
```

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ERR LOC  OBJECT                LINE      SOURCE STATEMENT
    0122 5700                   271                      DCB     57H, 00H                ;2784
    0124 5C03              R    272                      DCW             IDLE_MAP_PW_8
    0126 6400                   273                      DCB     64H, 00H                ;3200
    0128 6403              R    274                      DCW             IDLE_MAP_PW_9
                                275 ;
                                276 ;MAP pulse width calibation tables, first word indicates no. of break
                                277 ;points                  NNNN
                                278 ;                        MAPi,  Yi
                                279 ;                                SSSi
                                280 ;Yi= HSO1 PW (solenoid off time)/100H, unsigned positive short integer
                                281 ;       SSSi= slope X 100H
                                282 ;WOT: wide open throttle, CT: closed throttle, PT: part-throttle
                                283 ;
    012A 0300                   284 PT_MAP_PW_1:         DCW     0003H                   ;512 RPM
    012C 0A35                   285                      DCB     0AH, 35H
    012E 0000                   286                      DCW                     0000H
    0130 2135                   287                      DCB     21H, 35H
    0132 0000                   288                      DCW                     0000H
    0134 3E35                   289                      DCB     3EH, 35H
                                290
    0136 0300                   291 PT_MAP_PW_2:         DCW     0003H                   ;800
    0138 0A35                   292                      DCB     0AH, 35H
    013A 0000                   293                      DCW                     0000H
    013C 2135                   294                      DCB     21H, 35H
    013E 0000                   295                      DCW                     0000H
    0140 3E35                   296                      DCB     3EH, 35H
    0142 0000                   297                      DCW                     0000H
                                298
    0144 0300                   299 PT_MAP_PW_3:         DCW     0003H                   ;992
    0146 0944                   300                      DCB     09H, 44H
    0148 ECFF                   301                      DCW                     0FFECH
    014A 2242                   302                      DCB     22H, 42H
    014C 0000                   303                      DCW                     0000H
    014E A442                   304                      DCB     0A4H, 42H
                                305
    0150 0C00                   306 PT_MAP_PW_4:         DCW     000CH                   ;1184
    0152 0944                   307                      DCB     09H, 44H
    0154 0400                   308                      DCW                     0004H
    0156 4445                   309                      DCB     44H, 45H
    0158 1C00                   310                      DCW                     001CH
    015A 4D46                   311                      DCB     4DH, 46H
    015C 0000                   312                      DCW                     0000H
    015E 5746                   313                      DCB     57H, 46H
    0160 0000                   314                      DCW                     0000H
    0162 6446                   315                      DCB     64H, 46H
    0164 A100                   316                      DCW                     00A1H
    0166 7752                   317                      DCB     77H, 52H
    0168 1600                   318                      DCW                     0016H
    016A 8E54                   319                      DCB     8EH, 54H
    016C 5500                   320                      DCW                     0055H
    016E 9757                   321                      DCB     97H, 57H
    0170 5A00                   322                      DCW                     005AH
    0172 A85D                   323                      DCB     0A8H, 5DH
    0174 56FE                   324                      DCW                     0FE56H
    0176 B14E                   325                      DCB     0B1H, 4EH
    0178 34FF                   326                      DCW                     0FF34H
    017A C042                   327                      DCB     0C0H, 42H
    017C B4FE                   328                      DCW                     0FEB4H
    017E CA35                   329                      DCB     0CAH, 35H
                                330
    0180 0C00                   331 PT_MAP_PW_5:         DCW     000CH                   ;1408
    0182 0950                   332                      DCB     09H, 50H
    0184 CCFF                   333                      DCW                     0FFCCH
    0186 3A46                   334                      DCB     3AH, 46H
    0188 0000                   335                      DCW                     0000H
    018A 4446                   336                      DCB     44H, 46H
    018C 5000                   337                      DCW                     0050H
    018E 574C                   338                      DCB     57H, 4CH
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ERR LOC  OBJECT           LINE      SOURCE STATEMENT
    0190 2700             339                    DCW     0027H
    0192 644E             340                    DCB     64H, 4EH
    0194 EFFF             341                    DCW     0FFEFH
    0196 734D             342                    DCB     73H, 4DH
    0198 8900             343                    DCW     0089H
    019A 8054             344                    DCB     80H, 54H
    019C E4FF             345                    DCW     0FFE4H
    019E 9252             346                    DCB     92H, 52H
    01A0 0000             347                    DCW     0000H
    01A2 A052             348                    DCB     0A0H, 52H
    01A4 D9FF             349                    DCW     0FFD9H
    01A6 AD50             350                    DCB     0ADH, 50H
    01A8 CCFF             351                    DCW     0FFCCH
    01AA CA4A             352                    DCB     0CAH, 4AH
    01AC E7FD             353                    DCW     0FDE7H
    01AE D435             354                    DCB     0D4H, 35H
                          355
    01B0 0A00             356  PT_MAP_PW_6:      DCW     000AH           ;1600
    01B2 0950             357                    DCB     09H, 50H
    01B4 E1FF             358                    DCW     0FFE1H
    01B6 3A4A             359                    DCB     3AH, 4AH
    01B8 1500             360                    DCW     0015H
    01BA 524C             361                    DCB     52H, 4CH
    01BC 0000             362                    DCW     0000H
    01BE 644C             363                    DCB     64H, 4CH
    01C0 6B00             364                    DCW     006BH
    01C2 7754             365                    DCB     77H, 54H
    01C4 F3FF             366                    DCW     0FFF3H
    01C6 8A53             367                    DCB     8AH, 53H
    01C5 0B00             368                    DCW     000BH
    01CA A054             369                    DCB     0A0H, 54H
    01CC 0000             370                    DCW     0000H
    01CE B154             371                    DCB     0B1H, 54H
    01D0 0000             372                    DCW     0000H
    01D2 C054             373                    DCB     0C0H, 54H
    01D4 74FE             374                    DCW     0FE74H
    01D6 D435             375                    DCB     0D4H, 35H
                          376
    01D8 0B00             377  PT_MAP_PW_7:      DCW     000BH           ;1792
    01DA 0950             378                    DCB     09H, 50H
    01DC ECFF             379                    DCW     0FFECH
    01DE 3A4C             380                    DCB     3AH, 4CH
    01E0 0000             381                    DCW     0000H
    01E2 4D4C             382                    DCB     4DH, 4CH
    01E4 1600             383                    DCW     0016H
    01E6 644E             384                    DCB     64H, 4EH
    01E8 4900             385                    DCW     0049H
    01EA 8056             386                    DCB     80H, 56H
    01EC 0000             387                    DCW     0000H
    01EE 9256             388                    DCB     92H, 56H
    01F0 2400             389                    DCW     0024H
    01F2 A058             390                    DCB     0A0H, 58H
    01F4 0F00             391                    DCW     000FH
    01F6 B159             392                    DCB     0B1H, 59H
    01F8 CDFF             393                    DCW     0FFCDH
    01FA C056             394                    DCB     0C0H, 56H
    01FC 5AFE             395                    DCW     0FE5AH
    01FE D435             396                    DCB     0D4H, 35H
    0200 0000             397                    DCW     0000H
    0202 E735             398                    DCB     0E7H, 35H
                          399
    0204 0B00             400  PT_MAP_PW_8:      DCW     000BH           ;1984
    0206 0950             401                    DCB     09H, 50H
    0208 E9FF             402                    DCW     0FFE9H
    020A 354C             403                    DCB     35H, 4CH
    020C 0000             404                    DCW     0000H
    020E 484C             405                    DCB     48H, 4CH
    0210 2D00             406                    DCW     002DH
```

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ERR LOC  OBJECT                LINE        SOURCE STATEMENT
    0212 6451                   407                         DCB     64H, 51H
    0214 2800                   408                         DCW                 0028H
    0216 7754                   409                         DCB     77H, 54H
    0218 000D                   410                         DCW                 000DH
    021A 8A55                   411                         DCB     8AH, 55H
    021C E9FF                   412                         DCW                 0FFE9H
    021E A053                   413                         DCB     0A0H, 53H
    0220 1800                   414                         DCW                 0018H
    0222 B555                   415                         DCB     0B5H, 55H
    0224 A3FF                   416                         DCW                 0FFA3H
    0226 C051                   417                         DCB     0C0H, 51H
    0228 9AFE                   418                         DCW                 0FE9AH
    022A D435                   419                         DCB     0D4H, 35H
    022C 0000                   420                         DCW                 0000H
    022E E735                   421                         DCB     0E7H, 35H
                                422
    0230 0B00                   423     PT_MAP_PW_9:        DCW     000BH               ;2208
    0232 0950                   424                         DCB     09H, 50H
    0234 E9FF                   425                         DCW                 0FFE9H
    0236 354C                   426                         DCB     35H, 4CH
    0238 0000                   427                         DCW                 0000H
    023A 484C                   428                         DCB     48H, 4CH
    023C 2400                   429                         DCW                 0024H
    023E 6450                   430                         DCB     64H, 50H
    0240 4000                   431                         DCW                 0040H
    0242 8057                   432                         DCB     80H, 57H
    0244 2A00                   433                         DCW                 002AH
    0246 925A                   434                         DCB     92H, 5AH
    0248 1200                   435                         DCW                 0012H
    024A A05B                   436                         DCB     0A0H, 5BH
    024C 0000                   437                         DCW                 0000H
    024E AD5B                   438                         DCB     0ADH, 5BH
    0250 D8FF                   439                         DCW                 0FFD8H
    0252 C05B                   440                         DCB     0C0H, 5BH
    0254 40FE                   441                         DCW                 0FE40H
    0256 D435                   442                         DCB     0D4H, 35H
    0258 0000                   443                         DCW                 0000H
    025A E735                   444                         DCB     0E7H, 35H
                                445
    025C 0B00                   446     PT_MAP_PW_10:       DCW     000BH               ;2400
    025E 0950                   447                         DCB     09H, 50H
    0260 C7FF                   448                         DCW                 0FFC7H
    0262 3A45                   449                         DCB     3AH, 45H
    0264 0000                   450                         DCW                 0000H
    0266 4845                   451                         DCB     48H, 45H
    0268 6B00                   452                         DCW                 006BH
    026A 5B4D                   453                         DCB     5BH, 4DH
    026C 0000                   454                         DCW                 0000H
    026E 6E4D                   455                         DCB     6EH, 4DH
    0270 2400                   456                         DCW                 0024H
    0272 8A51                   457                         DCB     8AH, 51H
    0274 4E00                   458                         DCW                 004EH
    0276 9755                   459                         DCB     97H, 55H
    0278 3A00                   460                         DCW                 003AH
    027A AD5A                   461                         DCB     0ADH, 5AH
    027C 1300                   462                         DCW                 0013H
    027E BA5B                   463                         DCB     0BAH, 5BH
    0280 31FE                   464                         DCW                 0FE31H
    0282 CF35                   465                         DCB     0CFH, 35H
    0284 0000                   466                         DCW                 0000H
    0286 DE35                   467                         DCB     0DEH, 35H
                                468
    0288 0900                   469     PT_MAP_PW_11:       DCW     0009H               ;2784
    028A 4850                   470                         DCB     48H, 50H
    028C BDFF                   471                         DCW                 0FFBDH
    028E 5B4B                   472                         DCB     5BH, 4BH
    0290 4000                   473                         DCW                 0040H
    0292 7351                   474                         DCB     73H, 51H
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ERR LOC  OBJECT          LINE        SOURCE STATEMENT
    0294 1C00            475                         DCW     001CH
    0296 7C52            476                         DCB     7CH, 52H
    0298 4200            477                         DCW     0042H
    029A 9759            478                         DCB     97H, 59H
    029C 4500            479                         DCW     0045H
    029E AD5F            480                         DCB     0ADH, 5FH
    02A0 0000            481                         DCW     0000H
    02A2 BA5F            482                         DCB     0BAH, 5FH
    02A4 00FE            483                         DCW     0FE00H
    02A6 CF35            484                         DCB     0CFH, 35H
    02A8 0000            485                         DCW     0000H
    02AA E735            486                         DCB     0E7H, 35H
                         487
    02AC 0900            488   PT_MAP_PW_12:         DCW     0009H           ;3200
    02AE 4450            489                         DCB     44H, 50H
    02B0 7BFF            490                         DCW     0FF7BH
    02B2 5B44            491                         DCB     5BH, 44H
    02B4 F3FF            492                         DCW     0FFF3H
    02B6 6E43            493                         DCB     6EH, 43H
    02B8 7A00            494                         DCW     007AH
    02BA 854E            495                         DCB     85H, 4EH
    02BC BD00            496                         DCW     008DH
    02BE 9C5F            497                         DCB     9CH, 5FH
    02C0 60FF            498                         DCW     0FF60H
    02C2 A45A            499                         DCB     0A4H, 5AH
    02C4 E9FF            500                         DCW     0FFE9H
    02C6 BA58            501                         DCB     0BAH, 58H
    02C8 D0FD            502                         DCW     0FD00H
    02CA CA35            503                         DCB     0CAH, 35H
    02CC 0000            504                         DCW     0000H
    02CE DE35            505                         DCB     0DEH, 35H
                         506
    02D0 0800            507   PT_MAP_PW_13:         DCW     0008H           ;3584
    02D2 5753            508                         DCB     57H, 53H
    02D4 0000            509                         DCW     0000H
    02D6 7353            510                         DCB     73H, 53H
    02D8 1C00            511                         DCW     001CH
    02DA 8555            512                         DCB     85H, 55H
    02DC 3B00            513                         DCW     003BH
    02DE 9258            514                         DCB     92H, 58H
    02E0 1C00            515                         DCW     001CH
    02E2 A45A            516                         DCB     0A4H, 5AH
    02E4 2700            517                         DCW     0027H
    02E6 B15C            518                         DCB     0B1H, 5CH
    02E8 0000            519                         DCW     0000H
    02EA BA5C            520                         DCB     0BAH, 5CH
    02EC 25FE            521                         DCW     0FE25H
    02EE CF35            522                         DCB     0CFH, 35H
                         523
    02F0 0300            524   WOT_MAP_PW_1:         DCW     0003H           ;992
    02F2 C042            525                         DCB     0C0H, 42H
    02F4 E7FC            526                         DCW     0FCE7H
    02F6 CA23            527                         DCB     0CAH, 23H
    02F8 9AFC            528                         DCW     0FC9AH
    02FA D401            529                         DCB     0D4H, 01H
                         530
    02FC 0400            531   WOT_MAP_PW_2:         DCW     0004H           ;1408
    02FE AD50            532                         DCB     0ADH, 50H
    0300 B0FF            533                         DCW     0FFB0H
    0302 C04A            534                         DCB     0C0H, 4AH
    0304 1AFC            535                         DCW     0FC1AH
    0306 CA23            536                         DCB     0CAH, 23H
    0308 6603            537                         DCW     0366H
    030A C001            538                         DCB     0C0H, 01H
                         539
    030C 0400            540   WOT_MAP_PW_3:         DCW     0004H           ;2016
    030E B555            541                         DCB     0B5H, 55H
    0310 CDFB            542                         DCW     0FBCDH
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ERR LOC  OBJECT          LINE        SOURCE STATEMENT
    0312 BA40            543                     DCB     0BAH, 40H
    0314 80F5            544                     DCW                     0F580H
    0316 C001            545                     DCB     0C0H, 01H
    0318 0000            546                     DCW                     0000H
    031A CA01            547                     DCB     0CAH, 01H
                         548
    031C 0200            549  IDLE_MAP_PW_1:     DCW     0002H                   ;512
    031E 3F01            550                     DCB     3FH, 01H
    0320 0000            551                     DCW                     0000H
    0322 5201            552                     DCB     52H, 01H
                         553
    0324 0400            554  IDLE_MAP_PW_2:     DCW     0004H                   ;800
    0326 0930            555                     DCB     09H, 30H
    0328 0000            556                     DCW                     0000H
    032A 1A30            557                     DCB     1AH, 30H
    032C 0000            558                     DCW                     0000H
    032E 3F30            559                     DCB     3FH, 30H
    0330 0000            560                     DCW                     0000H
    0332 5230            561                     DCB     52H, 30H
                         562
    0334 0200            563  IDLE_MAP_PW_3:     DCW     0002H                   ;992
    0336 0935            564                     DCB     09H, 35H
    0338 0000            565                     DCW                     0000H
    033A 6935            566                     DCB     69H, 35H
                         567
    033C 0200            568  IDLE_MAP_PW_4:     DCW     0002H                   ;1184
    033E 0944            569                     DCB     09H, 44H
    0340 0000            570                     DCW                     0000H
    0342 4444            571                     DCB     44H, 44H
                         572
    0344 0200            573  IDLE_MAP_PW_5:     DCW     0002H                   ;1408
    0346 0950            574                     DCB     09H, 50H
    0348 BBFF            575                     DCW                     0FFBBH
    034A 4440            576                     DCB     44H, 40H
                         577
    034C 0200            578  IDLE_MAP_PW_6:     DCW     0002H                   ;1600
    034E 0950            579                     DCB     09H, 50H
    0350 C6FF            580                     DCW                     0FFC6H
    0352 3546            581                     DCB     35H, 46H
                         582
    0354 0200            583  IDLE_MAP_PW_7:     DCW     0002H                   ;1984
    0356 0950            584                     DCB     09H, 50H
    0358 D2FF            585                     DCW                     0FFD2H
    035A 3548            586                     DCB     35H, 48H
                         587
    035C 0200            588  IDLE_MAP_PW_8:     DCW     0002H                   ;2784
    035E 0950            589                     DCB     09H, 50H
    0360 E3FF            590                     DCW                     0FFE3H
    0362 354B            591                     DCB     35H, 4BH
                         592
    0364 0200            593  IDLE_MAP_PW_9:     DCW     0002H                   ;3200
    0366 0953            594                     DCB     09H, 53H
    0368 DEFF            595                     DCW                     0FFDEH
    036A 354D            596                     DCB     35H, 4DH
                         597  ;
                         598  ;CALPOT_TRIM: CALPOT based additive HSO pulse width correction factor
                         599  ;                               NNNN            no. of break points
                         600  ;                             Xi              Calpot voltage HEX count
                         601  ;                                Yi           additive correction factor
                         602  ;                                     SSSi    slope *100H
                         603  ;Yi=(HSO.1 pulse width)/100H, signed short integer
                         604  ;   00 to 7FH is positive; FFH to 80H is negative
                         605  ;
    036C 0400            606  CALPOT_TRIM:           DCW     0004
    036E 44D0            607                     DCB     44H, 0D0H
    0370 1101            608                     DCW                     0111H
    0372 7100            609                     DCB     71H, 00H
    0374 0000            610                     DCW                     0000H
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ERR LOC  OBJECT          LINE      SOURCE STATEMENT
    0376 B200             611                    DCB     0B2H, 00H
    0378 8001             612                    DCW                     0180H
    037A D230             613                    DCB     0D2H, 30H
                          614
                          615  ;
                          616  ;RUN Mode HSO pulse width multiplication factor calibration table.
                          617  ;first word indicates no. of break points
                          618  ;Cool_temp HEX count is in low temp scaling range, i.e., with 10K pullup
                          619  ;(1K pullup switched out by P1.0) = F8H to 33H (-40 C to 60 C)
                          620  ;Yi = (pulse width multiplication factor)/100H, signed short integer
                          621  ;     00 to 7F (0 to +127), FF to 80 (-1 to -128)
                          622  ;     multiplication factor of 1 = 00H
                          623  ;SSSi = slope X 100H
                          624  ;                              NNNN
                          625  ;                              COOL_TEMP,  Yi
                          626  ;                                          SSSi
    037C                  627  L_COOL_TEMP_PW_MULT_TBL:
    037C 0700             628                    DCW     0007H
    037E 3000             629                    DCB     30H, 00H                ;59 C
    0380 0000             630                    DCW                     0000H
    0382 6000             631                    DCB     60H, 00H                ;51 C
    0384 0000             632                    DCW                     0000H
    0386 9300             633                    DCB     93H, 00H                ;18 C
    0388 B7F8             634                    DCW                     0F8B7H
    038A 9ACD             635                    DCB     9AH, 0CDH               ;14 C
    038C 60FE             636                    DCW                     0FE60H
    038E AAB3             637                    DCB     0AAH, 0B3H              ;10 C
    0390 E5FE             638                    DCW                     0FEE5H
    0392 D880             639                    DCB     0D8H, 80H               ;-10C
    0394 0000             640                    DCW                     0000H
    0396 F080             641                    DCB     0F0H, 80H               ;-31C
                          642  ;
                          643  ;RUN Mode HSO pulse width multiplaction factor calibration table
                          644  ;first word indicates no. of break points
                          645  ;Cool_temp HEX count is in high temp scaling range, i.e., with 1K pullup
                          646  ;(1K pullup switched in by P1.0) = E5H to 4DH (30 C to 120 C)
                          647  ;Yi = (pulse width multiplication factor)/100H, signed short integer
                          648  ;      00 to 7F (0 to +127), FF to 80 (-1 to -128)
                          649  ;      multiplication factor of 1 =00H
                          650  ;SSSi = slope X 100H
                          651  ;                              NNNN
                          652  ;                              COOL_TEMP,  Yi
                          653  ;                                          SSSi
    0398                  654  H_COOL_TEMP_PW_MULT_TBL:
    0398 0500             655                    DCW     0005H
    039A 5C00             656                    DCB     5CH, 00H                ;110 C
    039C 0000             657                    DCW                     0000H
    039E 6D00             658                    DCB     6DH, 00H                ;
    03A0 0000             659                    DCW                     0000H
    03A2 9400             660                    DCB     94H, 00H                ;80 C
    03A4 0000             661                    DCW                     0000H
    03A6 A800             662                    DCB     0A8H, 00H               ;70 C
    03A8 0000             663                    DCW                     0000H
    03AA E500             664                    DCB     0E5H, 00H               ;30 C
                          665  ;
                          666  ;RUN mode deceleration leanout pulse width calibration table
                          667  ;first word indicates no. of break points
                          668  ;Xi = DELTA MAP = (DECEL_MAP_SW_PT_L - MAP) = 00 to FF (0 to +255)
                          669  ;Yi = decel pulse width in higher byte counts of timer1 = 00 to FF
                          670  ;(0 to +255).          SSSi = slope X 100H
                          671  ;                              NNNN
                          672  ;                              DELTA,Yi
                          673  ;                              MAP             SSSi
                          674  ;
    03AC 0600             675  DECEL_PW_TABLE:       DCW     0006H
    03AE 0203             676                    DCB     02H, 03H
    03B0 8001             677                    DCW                     0180H
    03B2 0406             678                    DCB     04H, 06H
```

```
ERR LOC  OBJECT                LINE        SOURCE STATEMENT
    03B4 0002                   679                    DCW                 0200H
    03B6 060A                   680                    DCB     06H, 0AH
    03B8 4002                   681                    DCW                 0240H
    03BA 1225                   682                    DCB     12H, 25H
    03BC C900                   683                    DCW                 00C9H
    03BE 2030                   684                    DCB     20H, 30H
    03C0 0000                   685                    DCW                 0000H
    03C2 3030                   686                    DCB     30H, 30H
                                687
    03C4                        688    END

ASSEMBLY COMPLETED.   NO ERROR(S) FOUND.
```

```
SOURCE FILE: DATA\HSO.ASM
OBJECT FILE: DATA\HSO.OBJ
ERR LOC  OBJECT                  LINE        SOURCE STATEMENT
                                    1   $TITLE('HSO.ASM: Module for generating 2 identical PWM outputs')
                                    2   HSO     MODULE
                                    3   ;
                                    4   ; This program provides 2 identical PWM outputs on HSO.1 and HSO.2
                                    5   ; FMS_PW_AVE        average FMS ON (HSO off) time for both outputs
                                    6   ; FMS_AVE_OFF_PERIOD    average FMS OFF (HSO on) time for both outputs
                                    7   ; HSO_PERIOD_1 = FMS_PW_AVE + FMS_AVE_OFF_PERIOD = Period of pulse
                                    8   ; average FMS PW and FMS off period are updated only once per every
                                        9   ; HSO period.
    0000                           10   RSEG
                                   11
                                   12   EXTRN   FMS_PW_SUM       :LONG
                                   13   EXTRN   FMS_PW_COUNT     :WORD
                                   14   EXTRN   FMS_AVE_PW       :WORD
                                   15   EXTRN   FMS_AVE_OFF_PERIOD :WORD
                                   16   EXTRN   HSO_PERIOD_1     :WORD
                                   17   EXTRN   HSO1_ON_TIME     :WORD
                                   18   EXTRN   HSO1_OFF_TIME    :WORD
                                   19   EXTRN   HSO_TIME         :WORD
                                   20   EXTRN   TIMER1           :WORD
                                   21   EXTRN   HSO_COMMAND      :BYTE
                                   22   EXTRN   HSO_OLD_STAT     :BYTE
                                   23   EXTRN   HSO_NEW_STAT     :BYTE
                                   24   EXTRN   IOS0             :BYTE
                                   25   EXTRN   MODE_FLAG        :BYTE
                                   26   ;
                                   27   PUBLIC  HSO_EXEC_INT
    0000                           28   CSEG
                                   29   ;
                                   30   ;HSO Executed Interrupt
                                   31   ;
    0000                           32   HSO_EXEC_INT:
    0000 F2                        33      PUSHF
    0001 51060000          E       34      ANDB    HSO_NEW_STAT, IOS0, #06H  ;read new status of HSO.1 & 2
                                   35   ;
                                   36   ;Determine if HSO is disabled by MODE_FLAG
                                   37   ;
    0005 390012            E       38      JBS     MODE_FLAG, 1, CHECK_HSO_STAT ;jump if HSO is enabled or else
    0008 B13100            E       39      LDB     HSO_COMMAND, #00110001B      ;disable HSO.1 by setting it
    000B 44000000          E       40      ADD     HSO_TIME, TIMER1, HSO1_OFF_TIME ;high at a delay of
                                   41                                          ;HSO1_OFF_TIME
    000F FD                        42      NOP                                 ;wait for the first command
    0010 FD                        43      NOP                                ;to be executed
    0011 B13200            E       44      LDB     HSO_COMMAND, #00110010B         ;disable HSO.2 by setting it
    0014 44000000          E       45      ADD     HSO_TIME, TIMER1, HSO1_OFF_TIME ;high at a delay of
                                   46                                              ;HSO1_OFF_TIME
    0018 204A                      47      BR      HSO_CHECK_DONE
                                   48
    001A                           49   CHECK_HSO_STAT:
    001A 980000            E       50      CMPB    HSO_OLD_STAT, HSO_NEW_STAT
    001D DF45                      51      JE      HSO_CHECK_DONE              ;if status hasn't changed
    001F 940000            E       52       XORB   HSO_OLD_STAT, HSO_NEW_STAT  ;a set bit indicates a change
                                   53
    0022                           54   CHECK_HSO_1:
    0022 310029            E       55      JBC     HSO_OLD_STAT, 1, CHECK_HSO_2    ;jump if no change in state
                                   56                                              ;for HSO.1
    0025 390009            E       57      JBS     HSO_NEW_STAT, 1, SET_OFF_1      ;jump if it's a low to high
                                   58                                              ;transition
    0028                           59   SET_ON_1:
    0028 B13100            E       60      LDB     HSO_COMMAND, #00110001B     ;set timer1 for HSO.1, time to
    002B 44000000          E       61      ADD     HSO_TIME, TIMER1, HSO1_OFF_TIME ;set pin = current Timer1
                                   62                                          ;value.
```

```
ERR LOC  OBJECT              LINE      SOURCE STATEMENT
    002F 201D                  63         BR      CHECK_HSO_2                    ;+ time for pin to be low
                               64     ;average FMS PW and OFF period are updated and then used for setting the
                               65     ;on and off period of the next HSO cycle
                               66     ;
    0031                       67     SET_OFF_1:
    0031 8C0000          E     68         DIVU    FMS_PW_SUM, FMS_PW_COUNT       ;calculate average FMS_PW
    0034 A00000          E     69         LD      FMS_AVE_PW, FMS_PW_SUM         ;update FMS PW
    0037 48000000        E     70         SUB     FMS_AVE_OFF_PERIOD, HSO_PERIOD_1, FMS_AVE_PW
                               71                                                ;update ave. FMS off period
    003B A00000          E     72         LD      HSO1_ON_TIME, FMS_AVE_OFF_PERIOD ;update HSO1_ON_TIME
    003E A00000          E     73         LD      HSO1_OFF_TIME, FMS_AVE_PW      ;update HSO1_OFF_TIME
    0041 0100            E     74         CLR     FMS_PW_SUM                   ;initialize PW accumulator &
    0043 0102            E     75         CLR     FMS_PW_SUM+2                 ;counter for the next cycle
    0045 0100            E     76         CLR     FMS_PW_COUNT                 ;
                               77                                              ;once per period only
    0047 B11100          E     78         LDB     HSO_COMMAND, #000100018      ;set timer1 for HSO.1, time to
    004A 44000000        E     79         ADD     HSO_TIME, TIMER1, HSO1_ON_TIME  ;clear pin = current Timer1
                               80                                             ;value + time for pin to be high
    004E                       81     CHECK_HSO_2:
    004E 320013          E     82         JBC     HSO_OLD_STAT, 2, HSO_CHECK_DONE ;jump if no change in
                               83                                             ;for HSO.2
    0051 3A0009          E     84         JBS     HSO_NEW_STAT, 2, SET_OFF_2     ;jump if it's a low to high
                               85                                                 ;transition
    0054                       86     SET_ON_2:
    0054 B13200          E     87         LDB     HSO_COMMAND, #001100108   ;set timer1 for HSO.2, time to
    0057 44000000        E     88         ADD     HSO_TIME, TIMER1, HSO1_OFF_TIME ;set pin= current Timer1
    005B 2007                  89         BR      HSO_CHECK_DONE          ;value + time for pin to be low
                               90
    005D                       91     SET_OFF_2:
    005D B11200          E     92         LDB     HSO_COMMAND, #000100108    ;set timer1 for HSO.2, time to
    0060 44000000        E     93         ADD     HSO_TIME, TIMER1, HSO1_ON_TIME  ;clear pin=current Timer1
                               94                                             ;value + time for pin to be high
    0064                       95     HSO_CHECK_DONE:
    0064 B00000          E     96             LDB     HSO_OLD_STAT, HSO_NEW_STAT      ;update HSO_OLD_STAT
    0067 F3                    97             POPF
    0068 F0                    98             RET
                               99
    0069                      100             END

ASSEMBLY COMPLETED,   NO ERROR(S) FOUND.
```

```
SOURCE FILE: DATA\SW_TMR.ASM
OBJECT FILE: DATA\SW_TMR.OBJ
ERR LOC  OBJECT                LINE      SOURCE STATEMENT
                                  1   $TITLE('SW_TMR.ASM: Module for servicing software timer interrupts')
                                  2   SW_TMR          MODULE
                                  3   ;
                                  4   ;This routine services software timer interrupts.
                                  5   ;
                                  6   ;SWT0 interrupt occurs every 5.5ms, it handles the following events:
                                  7   ;ACCUM_MAP is updated and MAP_COUNT is incremented every time,
                                  8   ;when 10H count is reached, AVE_MAP is updated; and MAP decel lean out
                                  9   ;flag (bit 6 of MODE_FLAG) is updated (approx. every 88ms), this flag is
                                 10   ;set if MAP is below DECEL_MAP_SW_PT_L and cleared if it is above DECEL_
                                 11   ;MAP_SW_PT_H, difference between DECEL_MAP_SW_PT_L and
                                 12   ;DECEL_MAP_SW_PT_H provides a hysteresis band
                                 13   ;
                                 14   ;SWT1 interrupt occurs every 125ms, it checks the coolant temperature
                                 15   ;sensor reading and then decides whether to switch in the 1K pullup
                                 16   ;resistor for changing the scaling factor or not
                                 17   ;
0000                             18   RSEG
                                 19
                                 20   EXTRN   ACCUM_MAP        :WORD
                                 21   EXTRN   AVE_MAP          :WORD
                                 22   EXTRN   COOL_TEMP        :WORD
                                 23   EXTRN   HSO_TIME         :WORD
                                 24   EXTRN   MAP              :WORD
                                 25   EXTRN   TIMER1           :WORD
                                 26   EXTRN   HALF_MIN_TIMER   :WORD
                                 27
                                 28   EXTRN   HSO_COMMAND      :BYTE
                                 29   EXTRN   IOPORT1          :BYTE
                                 30   EXTRN   IOS1             :BYTE
                                 31   EXTRN   IOS1_BAK         :BYTE
                                 32   EXTRN   MAP_COUNT        :BYTE
                                 33   EXTRN   MODE_FLAG        :BYTE
                                 34   PUBLIC  SW_TMR_INT
                                 35
0000                             36   CSEG
                                 37
                                 38   EXTRN   COOL_TEMP_SCALE_SP_H     :WORD
                                 39   EXTRN   COOL_TEMP_SCALE_SP_L     :WORD
                                 40   EXTRN   DECEL_MAP_SW_PT_H        :WORD
                                 41   EXTRN   DECEL_MAP_SW_PT_L        :WORD
                                 42   ;
                                 43   ;Software timer interrupt service routine
                                 44   ;
0000                             45   SW_TMR_INT:
0000 F2                          46           PUSHF
0001 900000          E           47           ORB     IOS1_BAK, IOS1      ;save HSO status for SW timers
0004 380008          E           48           JBS     IOS1_BAK, 0, SWT0   ;jump if SWT0 expired
0007 39003F          E           49           JBS     IOS1_BAK, 1, SWT1   ;jump if SWT1 expired
000A 3A0065          E           50           JBS     IOS1_BAK, 2, SWT2   ;jump if SWT2 expired
000D 2070                        51           BR      EXIT_SW_TMR_INT     ;no interrupt
                                 52
000F                             53   SWT0:
000F B11800          E           54           LDB     HSO_COMMAND, #00011000B  ;enable next SWT0 interrupt
0012 45BE0A0000      E           55           ADD     HSO_TIME, TIMER1, #0ABEH ;in 5.5ms
0017 640000          E           56           ADD     ACCUM_MAP, MAP           ;add MAP to accumulator
001A 1700            E           57           INCB    MAP_COUNT                ;increment MAP_COUNT
001C 991000          E           58           CMPB    MAP_COUNT,#10H           ;if counter is less than 16
001F DE20                        59           JLT     CHECK_SWT1               ;then exit
                                 60
0021                             61   CALC_AVE_MAP:
0021 080400          E           62           SHR     ACCUM_MAP, #4            ;divide by 10H
```

```
ERR LOC  OBJECT                LINE      SOURCE STATEMENT
    0024 A00000          E      63          LD      AVE_MAP, ACCUM_MAP      ;update AVE_MAP
    0027 0100            E      64          CLR     ACCUM_MAP               ;clear accumulator
    0029 1100            E      65          CLRB    MAP_COUNT               ;clear counter
                                66
    002B                        67  FLAG_DECEL:
    002B 8B01000000      E      68          CMP     MAP, DECEL_MAP_SW_PT_L  ;MAP > lower switch pt, check
    0030 D605                   69          JGE     CHECK_MAP_H_SW_PT       ;higher switch pt
    0032 914000          E      70          ORB     MODE_FLAG, #01000000B   ;MAP < LOW_SW_PT on decel,
    0035 200A                   71          BR      CHECK_SWT1              ;set flag to allow leanout
                                72
    0037                        73  CHECK_MAP_H_SW_PT:
    0037 8B01000000      E      74          CMP     MAP, DECEL_MAP_SW_PT_H  ;MAP within hysteresis band,
    003C DA03                   75          JLE     CHECK_SWT1              ;exit, do not change flag
    003E 71BF00          E      76          ANDB    MODE_FLAG, #10111111B   ;MAP > HIGH_SW_PT, clear flag
                                77                                          ;to cancel leanout
    0041                        78  CHECK_SWT1:
    0041 71FE00          E      79          ANDB    IOS1_BAK, #11111110B    ;clear bit 0 to flag SWT0 done
    0044 390002          E      80          JBS     IOS1_BAK, 1, SWT1       ;jump if SWT1 also expired
    0047 2036                   81          BR      EXIT_SW_TMR_INT
                                82  ;
                                83  ;SWT1: Controls coolant temperature sensor scaling resistor switching.
                                84  ;      P1.0 switches the 1K pullup resistor in and out for scale change.
                                85  ;      P1.0 = 0,       1K resistor switched in, in high temp scale range
                                86  ;      P1.0 = 1,       1K resistor switched out, in low temp scale range
                                87  ;
    0049                        88  SWT1:
    0049 B11900          E      89          LDB     HSO_COMMAND, #00011001B ;enable next SWT1 interrupt
    004C 4524F40000      E      90          ADD     HSO_TIME, TIMER1, #0F424H  ;in 125ms
                                91
    0051 30000C          E      92          JBC     IOPORT1, 0, IN_HIGH_TEMP_SCALE  ;in high temp scale if
                                93                                                  ;P1.0 is low
    0054                        94  IN_LOW_TEMP_SCALE:
    0054 8B01000000      E      95          CMP     COOL_TEMP, COOL_TEMP_SCALE_SP_H ;jump if coolant temp
    0059 DA0C                   96          JLE     SW_TO_HIGH_TEMP_SCALE    ;exceeds higher switch pt
                                97                                               ;(NTP sensor)
    005B                        98  SW_TO_LOW_TEMP_SCALE:
    005B 910100          E      99          ORB     IOPORT1, #00000001B     ;set P1.0 to switch out 1K
    005E 200A                  100          BR      RESET_SWT1_STATUS       ;scaling resistor
                               101
    0060                       102  IN_HIGH_TEMP_SCALE:
    0060 8B01000000      E     103          CMP     COOL_TEMP, COOL_TEMP_SCALE_SP_L ;jump if coolant temp
    0065 D6F4                  104          JGE     SW_TO_LOW_TEMP_SCALE ;falls below lower switch pt (NTP)
                               105
    0067                       106  SW_TO_HIGH_TEMP_SCALE:
    0067 71FE00          E     107          ANDB    IOPORT1, #11111110B     ;clear P1.0 to switch in 1K
                               108                                          ;scaling resistor
    006A                       109  RESET_SWT1_STATUS:
    006A 71FD00          E     110          ANDB    IOS1_BAK, #11111101B    ;clear bit 1 to flag SWT1 done
                               111
    006D                       112  CHECK_SWT2:
    006D 3A0002          E     113          JBS     IOS1_BAK, 2, SWT2       ;jump if SWT2 also expired
    0070 2000                  114          BR      EXIT_SW_TMR_INT
                               115  ;
                               116  ;SWT2: updates HALF_MIN_TIMER every 0.512 ms
                               117  ;
    0072 B11A00          E     118  SWT2:   LDB     HSO_COMMAND, #00011010B ;enable next SWT2 interrupt
    0075 4500010000      E     119          ADD     HSO_TIME, TIMER1, #0100H ;in 0.512 ms
    007A 0700            E     120          INC     HALF_MIN_TIMER          ;increment HALF_MIN_TIMER
                               121
    007C 71FB00          E     122          ANDB    IOS1_BAK, #11111011B    ;clear bit 2
                               123                                          ;to flag SWT2 done
    007F                       124  EXIT_SW_TMR_INT:
    007F F3                    125          POPF
    0080 F0                    126          RET
```

```
ERR LOC  OBJECT                LINE        SOURCE STATEMENT
                               127
    0081                       128           END

ASSEMBLY COMPLETED,   NO ERROR(S) FOUND.
```

```
SOURCE FILE: DATA\HSI_ATOD.ASM
OBJECT FILE: DATA\HSI_ATOD.OBJ
ERR LOC  OBJECT                LINE        SOURCE STATEMENT
                                 1   $TITLE('HSI_ATOD.ASM: - HSI and A to D Monitor')
                                 2   HSI_ATOD        MODULE
                                 3   ;
                                 4   ;This module monitors the HSI and A to D ports and services TIMER1
                                 5   ;overflow interrupt
                                 6   ;TIMER1 counts is extended to double word wide providing a real time
                                 7   ;clock of up to 2.386 hours at a resolution of 2 micoseconds.
                                 8   ;
                                 9   ;Engine RPM at HSI.2 is determined by counting time lapsed
                                10   ;between consecutive positive going edges of inverted HALL input.
                                11   ;Vehicle speed at HSI.1 is determined by counting time lapsed between
                                12   ;positive going edges of inverted SPEED input.
                                13   ;
                                14   ;A to D is triggered at a 1ms delay from positive edges of inverted
                                15   ;HALL
                                16   ;
  0000                          17   RSEG
                                18
                                19   EXTRN           PERIOD_TEMP     :LONG
                                20   EXTRN           RPM_PERIOD_90   :LONG
                                21   EXTRN           SPD_CONV_CONST  :LONG
                                22   EXTRN           VEH_SPD_PRD     :LONG
                                23
                                24   EXTRN           AX              :WORD
                                25   EXTRN           BX              :WORD
                                26   EXTRN           CX              :WORD
                                27   EXTRN           DX              :WORD
                                28   EXTRN           HSI_TIME        :WORD
                                29   EXTRN           HSO_TIME        :WORD
                                30   EXTRN           TIMER1          :WORD
                                31
                                32   EXTRN   RPM_OLD_TIME_LO         :WORD
                                33   EXTRN   RPM_OLD_TIME_HI         :WORD
                                34   EXTRN   TIMER_1_HI              :WORD
                                35   EXTRN   VEH_SPD_OLD_TM_LO       :WORD
                                36   EXTRN   VEH_SPD_OLD_TM_HI       :WORD
                                37
                                38   EXTRN   AD_RESULT_TABLE         :NULL
                                39   EXTRN           MPH             :WORD
                                40   EXTRN           RPM             :WORD
                                41
                                42   EXTRN           AL              :BYTE
                                43   EXTRN           AH              :BYTE
                                44   EXTRN           DL              :BYTE
                                45   EXTRN           DH              :BYTE
                                46
                                47   EXTRN   AD_COMMAND              :BYTE
                                48   EXTRN   AD_NUM                  :BYTE
                                49   EXTRN   AD_RESULT_LO            :BYTE
                                50   EXTRN   AD_RESULT_HI            :BYTE
                                51
                                52   EXTRN   HSI_STATUS              :BYTE
                                53   EXTRN   HSO_COMMAND             :BYTE
                                54   EXTRN   INT_MASK                :BYTE
                                55   EXTRN   IOS1                    :BYTE
                                56
                                57   EXTRN   HSI_D_AVAIL_FLAG        :BYTE
                                58   EXTRN   IOS1_BAK                :BYTE
                                59   EXTRN   MODE_FLAG               :BYTE
                                60   ;
                                61   ;CONSTANTS
                                62   ;
```

```
ERR LOC  OBJECT                LINE        SOURCE STATEMENT
     01F4                        63   ADC_DELAY       EQU     1F4H:WORD
                                 64   EXTRN   ZERO                    :WORD
                                 65   ;
                                 66   PUBLIC TIMER_OVF_INT, HSI_DATA_INT, HSI_UPDATE_CHECK
                                 67   PUBLIC ATOD_DONE_INT
                                 68   ;
                                 69   ;UPDATE RPM OR VEH SPEED READINGS
                                 70   ;
     0000                        71   CSEG
                                 72
     0000                        73 HSI_UPDATE_CHECK:
     0000 39001F          E      74   JBS     HSI_D_AVAIL_FLAG, 1, VEH_SPD_UPDATE ;veh speed data available
     0003 3A0002          E      75   JBS     HSI_D_AVAIL_FLAG, 2, RPM_UPDATE     ;no new RPM & MPH data
     0006 2033                   76   BR      END_CHECK
                                 77   ;
                                 78   ;each count in RPM_PERIOD_90 is 2 mico-s, and 0.131072 s in
                                 79   ;RPM_PERIOD_90+2
     0008                        80 RPM_UPDATE:
     0008 71FB00          E      81   ANDB    HSI_D_AVAIL_FLAG, #11111011B    ;clear flag.2
     0008 FA                     82   DI
     000C A00000          E      83   LD      PERIOD_TEMP, RPM_PERIOD_90      ;get current
     000F A00202          E      84   LD      PERIOD_TEMP+2, RPM_PERIOD_90+2  ;RPM_PERIOD_90
     0012 FB                     85   EI
     0013 A1E07000        E      86   LD      SPD_CONV_CONST, #70E0H          ;load RPM conversion factor
     0017 A1720002        E      87   LD      SPD_CONV_CONST+2, #0072H        ;
     001B 281F                   88   CALL    CALC_SPEED                      ;calculate RPM
     001D C00000          E      89   ST      SPD_CONV_CONST, RPM             ;store result
     0020 2019                   90   BR      END_CHECK
                                 91   ;
                                 92   ;each count in VEH_SPD_PRD is 2 mico-sec.,
                                 93   ;and 0.131072 s in VEH_SPD_PRD+2
     0022                        94 VEH_SPD_UPDATE:
     0022 51FD0100        E      95   ANDB    HSI_D_AVAIL_FLAG, 1,#11111101B  ;clear flag.1
     0026 FA                     96   DI
     0027 A00000          E      97   LD      PERIOD_TEMP, VEH_SPD_PRD      ;get current
     002A A00202          E      98   LD      PERIOD_TEMP+2, VEH_SPD_PRD+2  ;VEH_SPD_PRD
     002D FB                     99   EI
     002E A1E86E00        E     100   LD      SPD_CONV_CONST, #6EE8h        ;load MPH conversion
     0032 A1030002        E     101   LD      SPD_CONV_CONST+2, #0003H      ;constant
     0036 2804                  102   CALL    CALC_SPEED                    ;calculate MPH
     0038 C00000          E     103   ST      SPD_CONV_CONST, MPH           ;store result
                                104
     003B                       105 END_CHECK:
     003B F0                    106   RET
                                107 ;
                                108 ;RPM/MPH CONVERSION ROUNTINE
                                109 ;RPM=7270E0H/RPM_PERIOD_90 for RPM > 114,
                                110 ;RPM=7270E000H/(100H*RPM_PERIOD_90+2) for 114>RPM>0.45 and
                                111 ;RPM = 0 below 0.45. MPH=36EE8H/VEH_SPD_PRD, for MPH >3.
                                112 ;MPH=36EE800H/(100H*VEH_SPD_PRD+2) for 3>MPH>0.01. MPH=0 below0.01
                                113 ;RPM/MPH results returned to SPD_CONV_CONST register
     003C                       114 CALC_SPEED:
     003C 89000102        E     115   CMP     PERIOD_TEMP+2, #0100H   ;if greater than or equal to
     0040 D60C                  116         JGE     ZERO_SPEED                  ;set speed to 0.
     0042 89000002        E     117   CMP     PERIOD_TEMP+2, #ZERO    ;period wider than one word,
     0046 D70F                  118   JNE     CALC_LOW_SPEED          ;calculate low speeds
     0048 89000000        E     119   CMP     PERIOD_TEMP, #ZERO   ;period has non-zero value
     004C D704                  120   JNE     CALC_HIGH_SPEED   ;and within one word wide calc high speed
     004E                       121 ZERO_SPEED:
     004E 0100            E     122   CLR     SPD_CONV_CONST      ;period is zero, return zero result
     0050 2013                  123   BR      END_CALC_SPEED
     0052                       124 CALC_HIGH_SPEED:
     0052 8C0000          E     125   DIVU    SPD_CONV_CONST, PERIOD_TEMP  ;calculate RPM/MPH
     0055 200E                  126   BR      END_CALC_SPEED
```

```
ERR LOC  OBJECT                LINE        SOURCE STATEMENT
    0057                        127 CALC_LOW_SPEED:
    0057 D00800            E    128   SHLL    SPD_CONV_CONST, #8       ;equiv to multiply by 100H
    005A D00800            E    129   SHLL    PERIOD_TEMP, #8          ;to gain 1 more significant byte
    005D A00200            E    130   LD      SPD_CONV_CONST, SPD_CONV_CONST+2   ;align most significant
    0060 0102              E    131    CLR     SPD_CONV_CONST+2                  ;word for division
    0062 8C0200            E    132    DIVU    SPD_CONV_CONST, PERIOD_TEMP+2     ;calculate approx RPM/MPH
    0065                        133 END_CALC_SPEED:
    0065 F0                     134    RET
                                135    ;
                                136   ;TIMER OVERFLOW INTERRUPT SERVICE
                                137   ;TIMER_1_HI has a resolution of 0.131072 second
                                138   ;
    0066                        139 TIMER_OVF_INT:
    0066 F2                     140    PUSHF
    0067 900000            E    141    ORB     IOS1_BAK, IOS1           ;read and back up IO status
                                142
    006A                        143 CHECK_TMR1:
    006A 350005            E    144    JBC     IOS1_BAK, 5, TMR1_INT_DONE ;exit if no timer1 interrrupt
    006D 0700              E    145    INC     TIMER_1_HI               ;increment timer1 high byte count
    006F 71DF00            E    146    ANDB    IOS1_BAK, #11011111B     ;clear bit 5
                                147
    0072                        148 TMR1_INT_DONE:
    0072 F3                     149    POPF
    0073 F0                     150    RET
                                151    ;
                                152   ;HSI INTERRUPT SERVICE
                                153   ;HSI.1 for vehicle speed, HSI.2 for engine RPM
                                154   ;trigger A to D conversion
                                155   ;
    0074                        156 HSI_DATA_INT:
    0074 F2                     157    PUSHF
    0075 C800              E    158    PUSH    AX
    0077 C800              E    159    PUSH    BX
    0079 C800              E    160    PUSH    CX
    007B C800              E    161    PUSH    DX
    007D B00000            E    162    LDB     AL, HSI_STATUS           ;load status
    0080 A00000            E    163    LD      BX, HSI_TIME             ;get timer1, clear loading reg
    0083 A00000            E    164    LD      CX, TIMER_1_HI           ;get extended timer1 counts
    0086 3A0029            E    165    JBS     AL, 2, HSI1_DATA_AVAIL   ;HSI.1 made a transition ë
    0089 34003F            E    166    JBC     AL, 4, exit_hsi_int      ;return if no transitions at
                                167                                           ;HSI.1 & 2
    008C                        168 HSI2_DATA_AVAIL:
    008C 35003C            E    169    JBC     AL, 5, exit_hsi_int      ;return if current state of
                                170                                           ;HSI.2 is low
    008F                        171 HSI_2_HI:
                                172    ;
                                173    ;Set up A to D conversion to occur in 1ms from positive edges of HSI.2
                                174    ;AD_COMMAND initialized to ACH0 in FMC_MNTR routine
                                175    ;to avoid noises/interference when spark firing occurs
                                176    ;this trigger is not allowed when AD_READ is in control in START mode
                                177    ;
    008F 3E0008            E    178    JBS     AD_NUM, 6, NO_AD_CONV_CONT    ;jump if AD_READ is in control
    0092 B10F00            E    179    LDB     HSO_COMMAND, #00001111B       ;A to D triggered by HSO,start
    0095 45F4010000        E    180    ADD     HSO_TIME, TIMER1, #ADC_DELAY  ;converion in 1ms
                                181    ;
                                182    ;Determine and store away inverted HALL Pulse period
                                183    ;
    009A                        184 NO_AD_CONV_CONT:
    009A 48000000          E    185    SUB     RPM_PERIOD_90, BX, RPM_OLD_TIME_LO
    009E C00000            E    186    ST      BX, RPM_OLD_TIME_LO
    00A1 A00000            E    187    LD      BX, CX                   ;load TIMER_1_HI into BX register
    00A4 A80000            E    188    SUBC    BX, RPM_OLD_TIME_HI      ;
    00A7 C00200            E    189    ST      BX, RPM_PERIOD_90+2      ;RPM_PERIOD_90 limited to 2 words
                                190                                     ;wide
```

```
ERR LOC  OBJECT              LINE      SOURCE STATEMENT
    00AA C00000          E    191    ST      CX, RPM_OLD_TIME_HI
    00AD 910400          E    192    ORB     HSI_D_AVAIL_FLAG, #00000100B  ;set FLAG.2
    00B0 2019                 193    BR      EXIT_HSI_INT
                              194
    00B2                      195  HSI1_DATA_AVAIL:
    00B2 330016          E    196    JBC     AL, 3, EXIT_HSI_INT   ;return if current state of
                              197                                          ;HSI.1 is low
                              198  ;
                              199  ;determine and store away SPEED period
                              200  ;
    00B5                      201  HSI_1_HI:
    00B5 48000000        E    202     SUB     VEH_SPD_PRD, BX, VEH_SPD_OLD_TM_LO
    00B9 C00000          E    203     ST      BX, VEH_SPD_OLD_TM_LO
    00BC A00000          E    204     LD      BX, CX                        ;load TIMER_1_HI into BX
    00BF A80000          E    205     SUBC    BX, VEH_SPD_OLD_TM_HI         ;register
    00C2 C00200          E    206     ST      BX, VEH_SPD_PRD+2             ;VEH_SPD_PRD limited to
    00C5 C00000          E    207     ST      CX, VEH_SPD_OLD_TM_HI         ;2 words wide
    00C8 910200          E    208     ORB     HSI_D_AVAIL_FLAG, #00000010B  ;set FLAG.1
                              209
    00CB                      210  EXIT_HSI_INT:
    00CB CC00            E    211     POP     DX
    00CD CC00            E    212     POP     CX
    00CF CC00            E    213     POP     BX
    00D1 CC00            E    214     POP     AX
    00D3 F3                   215     POPF
    00D4 F0                   216     RET
                              217  ;
                              218  ;A to D complete interrupt
                              219  ;
                              220  ;AD_NUM.0-3 indicate current channel No., AD_NUM.6=1 :AD_READ in control
                              221  ;AD_NUM.6=0 :ATOD_DONE_INT in control, AD_NUM.7=0 flags A to D complete
                              222  ;AD_NUM.7=1 flags A to D in progress
                              223  ;
    00D5                      224  ATOD_DONE_INT:
    00D5 F2                   225     PUSHF
    00D6 C800            E    226     PUSH    AX
    00D8 C800            E    227     PUSH    DX
    00DA B10C00          E    228     LDB     INT_MASK, #00001100B    ;enable HSO and HSI date available
    00DD FB                   229     EI                              ;interrupts
    00DE 51C00000        E    230     ANDB    AL, AD_RESULT_LO, #11000000B    ;load lower order result
    00E2 B00000          E    231     LDB     AH, AD_RESULT_HI                ;load higher order result
    00E5 54000000        E    232     ADDB    DL, AD_NUM, AD_NUM              ;DL=AD_NUM*2
    00E9 710F00          E    233     ANDB    DL, #00001111B                  ;clear bits 6 and 7
    00EC AC0000          E    234     LDBZE   DX, DL                          ;expand DL to word wide
                              235
    00EF 994000          E    236     CMPB    AL, #01000000B          ;round up to single 8 bits
    00F2 D107                 237     JNH     NO_RND                  ;if needed
    00F4 99FF00          E    238     CMPB    AH, #0FFH               ;don't increment if AH=0FFH
    00F7 DF02                 239     JE      NO_RND
    00F9 1700            E    240     INCB    AH
                              241
    00FB                      242  NO_RND:
    00FB B00000          E    243     LDB     AL, AH                  ;align byte and change to word
    00FE 1100            E    244     CLRB    AH
    0100 C300000000      E    245     ST      AX, AD_RESULT_TABLE[DX] ;store result indexed by DX
                              246  ;
                              247  ;If routine in control, set up ACH for conversion
                              248  ;
    0105 3E0012          E    249     JBS     AD_NUM, 6, EXIT_AD_DONE ;jump if AD_READ is in control
    0108 1700            E    250     INCB    AD_NUM                  ;next ACH
    010A 710700          E    251     ANDB    AD_NUM, #07H            ;keep AD_NUM between 0 and 7
    010D 980000          E    252     CMPB    AD_NUM, ZERO            ;exit if AD_NUM=0
    0110 DF06                 253     JE      AD_ALL_DONE    ;or else continue A/D now
                              254
```

```
ERR LOC  OBJECT                LINE        SOURCE STATEMENT
    0112                        255   CONTINUE_AD:
    0112 55080000          E    256      ADDB    AD_COMMAND, AD_NUM, #1000B    ;start conversion now
    0116 2002                   257      BR      EXIT_AD_DONE
                                258
    0118                        259   AD_ALL_DONE:
    0118 1100              E    260      CLRB    AD_COMMAND     ;set HSO to trigger A to D,
                                261                             ;starting from ACH0
    011A                        262   EXIT_AD_DONE:
    011A 717F00            E    263      ANDB    AD_NUM, #01111111B      ;flag A to D completion
    011D CC00              E    264           POP     DX
    011F CC00              E    265           POP     AX
    0121 F3                     266           POPF
    0122 F0                     267           RET
                                268
    0123                        269           END

ASSEMBLY COMPLETED,   NO ERROR(S) FOUND.
```

```
SOURCE FILE: DATA\TABLE_LK.ASM
OBJECT FILE: DATA\TABLE_LK.OBJ
ERR LOC  OBJECT                  LINE      SOURCE STATEMENT
                                    1  $TITLE("TABLE_LK.ASM:Table Look-up Module - Propane Metering Cntrl")
                                    2  TABLE_LK        MODULE
                                    3  ;
                                    4  ;This module has routines to perform interpolations on calibration
                                    5  ;tables and look up table vector chart.  Calibration tables reside
                                    6  ;reside in ROM and is tabulated in CALIB_TB.INC. Routine call
                                    7  ;convention: load table address into TABLE_LABEL register.
                                    8  ;Tables are in the following format:
                                    9  ; TABLE_ADDR:     NNNN            ;n=no. of break points: 1 word
                                   10  ; X1, Y1, SSS1    ;Xi: 1 byte, Yi:  1 byte
                                   11  ; X2, Y2, SSS2    ;SSSi: 1 word
                                   12  ; Xi, Yi, SSSi    ;SSSi=100H*(Y(i+1)-Y(i))/(X(i+1)-X(i))
                                   13  ;                          Xn, Yn          ;last, nth, break point
                                   14  ;X is loaded into CX register and delta X is calculated and store in CX
                                   15  ;temporarily, SSSi is loaded into AX and BX(aligned as a long integer)
                                   16  ;Y=Yi + SSSi*(X - X(i))/100h
                                   17  ;result is passed back to calling program in registers AX and BX,
                                   18  ;aligned as a long integer
                                   19  ;
0000                               20  RSEG
                                   21
                                   22  EXTRN   TABLE_LABEL             :WORD
                                   23  EXTRN   AX                      :WORD
                                   24  EXTRN   AXL                     :LONG
                                   25  EXTRN   CX                      :WORD
                                   26  EXTRN   DX                      :WORD
                                   27  EXTRN   EX                      :WORD
                                   28  EXTRN   END_POINT               :WORD
                                   29  EXTRN   ZERO                    :WORD
                                   30  EXTRN   VECTOR_LABEL_L          :WORD
                                   31  EXTRN   VECTOR_LABEL_H          :WORD
                                   32  EXTRN   AL                      :BYTE
                                   33  EXTRN   AH                      :BYTE
                                   34  EXTRN   CL                      :BYTE
                                   35  EXTRN   CH                      :BYTE
                                   36  EXTRN   DL                      :BYTE
                                   37  EXTRN   DH                      :BYTE
                                   38  EXTRN   EL                      :BYTE
                                   39  EXTRN   EH                      :BYTE
                                   40  EXTRN   RPM_I_L                 :BYTE
                                   41  EXTRN   RPM_I_H                 :BYTE
                                   42
0000                               43  CSEG
                                   44
                                   45  PUBLIC  UNSIGNED_TABLE_LK_UP
                                   46  ;
                                   47  ;X is already in EL, table address is already in TABLE_LABEL
                                   48  ;Y is positive having values between 00 and FFH. Unsigned byte
                                   49  ;result is returned in AL, AH is zero extended.
                                   50  ;
0000                               51  UNSIGNED_TABLE_LK_UP:
0000 A20000              E         52    LD      DX, [TABLE_LABEL]+    ;get total no. of points from 1st word
0003 A00000              E         53    LD      END_POINT, TABLE_LABEL  ;get address of first break point
0006 0500                E         54    DEC     DX                      ;calculate address offset for
0008 7D0400              E         55    MULUB   DL, #4                  ;last break point
000B 640000              E         56    ADD     TABLE_LABEL, DX         ;starting with TABLE_LABEL pointing
                                   57                                    ;to last break point
000E A00000              E         58    LD      DX, TABLE_LABEL   ;record address of last break point in DX
0011                               59  CHECK_BR_PT:
0011 9A0000              E         60    CMPB    EL, [TABLE_LABEL]     ;jump if X is higher than
0014 D90D                          61    JH      THIS_BREAK_PT         ;Xi
0016 DF2C                          62    JE      USE_BR_PT
```

```
ERR LOC  OBJECT                LINE      SOURCE STATEMENT
    0018 880000          E      63     CMP     TABLE_LABEL, END_POINT  ;use break point if X is
    001B DF27                   64     JE      USE_BR_PT               ;the first point
    001D 69040000        E      65     SUB     TABLE_LABEL, #4         ;or else check the next lower break
    0021 27EE                   66     BR      CHECK_BR_PT             ;point
                                67
    0023                        68   THIS_BREAK_PT:
    0023 880000          E      69     CMP     TABLE_LABEL, DX         ;use break point if this is the last
    0026 DF1C                   70     JE      USE_BR_PT               ;point or else interpolate
                                71
    0028                        72   INTERPOLATION:
    0028 AC0000          E      73     LDBZE   EX, EL              ;extend X into word
    002B AE0000          E      74     LDBZE   CX, [TABLE_LABEL]   ;get Xi and extend into word
    002E 48000000        E      75     SUB     CX, EX, CX      ;calculate and store X-Xi in CX register
    0032 FE4F00020000    E      76     MUL     AXL, CX, 2[TABLE_LABEL]     ;calculate SSSi*(X-Xi)
    0038 0E0800          E      77     SHRAL   AXL, #8                     ;divide by 100H
    003B AF000100        E      78     LDBZE   CX, 1[TABLE_LABEL]          ;get Yi
    003F 640000          E      79     ADD     AX, CX                      ;Y=Yi + SSSi*(X-Xi)/100H
    0042 2004                   80     BR      EXIT_TBL_LOOKUP
    0044                        81   USE_BR_PT:
    0044 AF000100        E      82     LDBZE   AX, 1[TABLE_LABEL]          ;Y= Yi
                                83
    0048                        84   EXIT_TBL_LOOKUP:
    0048 F0                     85     RET
                                86
                                87   PUBLIC  SIGNED_TABLE_LK_UP
                                88   ;
                                89   ;X is already in EL, table address is already in TABLE_LABEL
                                90   ;Y is signed having values between 00 and 7FH for positive
                                91   ;values and FFH to 80H for negative values. Signed byte result
                                92   ;is returned in AL with sign extended to AH
                                93   ;
    0049                        94   SIGNED_TABLE_LK_UP:
    0049 A20000          E      95     LD      DX, [TABLE_LABEL]+  ;get total no. of points from 1st word
    004C A00000          E      96     LD      END_POINT, TABLE_LABEL  ;get address of first break point
    004F 0500            E      97     DEC     DX                  ;calculate address offset for
    0051 7D0400          E      98     MULUB   DL, #4              ;last break point
    0054 640000          E      99     ADD     TABLE_LABEL, DX     ;starting with TABLE_LABEL pointing to
                               100                                 ;last break point
    0057 A00000          E     101     LD      DX, TABLE_LABEL  ;record address of last break point in DX
    005A                       102   CHECK_BREAK_POINT:
    005A 9A0000          E     103     CMPB    EL, [TABLE_LABEL]       ;jump if X is higher than
    005D D900                  104     JH      THIS_BREAK_POINT        ;Xi
    005F DF2F                  105     JE      USE_BREAK_POINT
    0061 880000          E     106     CMP     TABLE_LABEL, END_POINT  ;use break point if X is
    0064 DF2A                  107     JE      USE_BREAK_POINT     ;the first point
    0066 69040000        E     108     SUB     TABLE_LABEL, #4     ;or else check the next lower break
    006A 27EE                  109     BR      CHECK_BREAK_POINT   ;point
                               110
    006C                       111   THIS_BREAK_POINT:
    006C 880000          E     112     CMP     TABLE_LABEL, DX     ;use break point if this is the last
    006F DF1F                  113     JE      USE_BREAK_POINT     ;point or else interpolate
                               114
    0071                       115   SIGNED_INTERPOLATION:
    0071 AC0000          E     116     LDBZE   EX, EL              ;get X and extend into word wide
    0074 AE0000          E     117     LDBZE   CX, [TABLE_LABEL]   ;get Xi and extend into word wide
    0077 48000000        E     118     SUB     CX, EX, CX    ;calculate and store X-Xi in CX register
    007B FE4F00020000    E     119     MUL     AXL, CX, 2[TABLE_LABEL]         ;calculate SSSi*(X-Xi)
    0081 0E0800          E     120     SHRAL   AXL, #8                         ;divide by 100H
    0084 83000100        E     121     LDB     CL, 1[TABLE_LABEL]              ;get Yi
    0088 740000          E     122     ADDB    AL, CL                          ;Y=Yi + SSSi*(X-Xi)/100H
    008B BC0000          E     123     LDBSE   AX, AL        ;return sign extended result in AX
    008E 2004                  124     BR      EXIT_TBL_LKUP
                               125
    0090                       126   USE_BREAK_POINT:
```

```
ERR LOC  OBJECT                LINE        SOURCE STATEMENT
    0090 BF000100          E    127     LDBSE   AX, 1[TABLE_LABEL]              ;Y= Yi , sign extended
                                128
    0094                        129   EXIT_TBL_LKUP:
    0094 F0                     130     RET
                                131
                                132   PUBLIC LOCATE_MAP_PW_TABLE
                                133
    0095                        134   LOCATE_MAP_PW_TABLE:
                                135   ;
                                136   ;look up MAP_PW_TABLE_LABEL, locate RPM_I_L and RPM_I_H, where RPM_I_L<
                                137   ;RPM_X < RPM_I_H; the corresponding table labels are stored in MAP_PW_L
                                138   ;and MAP_PW_H respectively
                                139   ;RPM_X is already in register CL
                                140   ;Vector tables are in the following format:
                                141   ;  VECTOR_TABLE:   NNNN   ;= No. of break points: 1 word
                                142   ;        X1     ;Xi: 1 word, e.g. RPM/32, high byte=00H
                                143   ;        YY1  ;vector label, e.g. CT_MAP_PW_1: 1 word
                                144   ;                        Xi              ;i-th X break point
                                145   ;                              YYi       ;i-th vector
                                146   ;                        Xn              ;last X break point
                                147   ;                              YYn       ;last vector label
                                148   ;
    0095 A20000            E    149      LD      DX, [TABLE_LABEL]+      ;get total no. of break points
    0098 A00000            E    150      LD      END_POINT, TABLE_LABEL  ;get address of first break point
    0098 0500              E    151      DEC     DX                ;calculate address offset for last
    0090 7D0400            E    152      MULUB   DL, #4            ;break point
    00A0 640000            E    153      ADD     TABLE_LABEL, DX   ;starting with VECTOR_LABEL pointing
                                154                                ;to last break point
    00A3 A00000            E    155      LD      DX, TABLE_LABEL   ;record address of last break pt. in DX
                                156
    00A6                        157   LOCATE_BR_PT:
    00A6 9A0000            E    158      CMPB    CL, [TABLE_LABEL]      ;;mp if X is higher than Xi
    00A9 D900                   159      JH      THIS_BRK_PT
    00AB DF21                   160      JE      USE_BRK_PT
    00AD 880000            E    161      CMP     TABLE_LABEL, END_POINT ;use break point if X is the
    00B0 DF1C                   162      JE      USE_BRK_PT             ;first point
    00B2 69040000          E    163      SUB     TABLE_LABEL, #4      ;or else check  the next lower
    00B6 27EE                   164      BR      LOCATE_BR_PT         ;break point
                                165
    00B8                        166   THIS_BRK_PT:
    00B8 880000            E    167      CMP     TABLE_LABEL, DX    ;use break point vector if this is the
    00BB DF11                   168      JE      USE_BRK_PT         ;last point or else get vectors and
                                169                                 ;break pts
    00BD                        170   GET_VECTOR:
    00BD B20000            E    171      LDB     RPM_I_L, [TABLE_LABEL]          ;get lower RPM break point
    00C0 A3000200          E    172      LD      VECTOR_LABEL_L, 2[TABLE_LABEL]  ;get MAP_PW table label
    00C4 B3000400          E    173      LDB     RPM_I_H, 4[TABLE_LABEL]         ;get higher RPM break point
    00C8 A3000600          E    174      LD      VECTOR_LABEL_H, 6[TABLE_LABEL]  ;get MAP_PW table label
    00CC 200E                   175      BR      EXIT_LOCATE_VECTOR
                                176
    00CE                        177   USE_BRK_PT:
    00CE B20000            E    178      LDB     RPM_I_L, [TABLE_LABEL]          ;RPM_X equal to break point
    00D1 A3000200          E    179      LD      VECTOR_LABEL_L, 2[TABLE_LABEL]  ;use same break pt. values
    00D5 B20000            E    180      LDB     RPM_I_H, [TABLE_LABEL]          ;higher and lower RPM_I and
    00D8 A3000200          E    181      LD      VECTOR_LABEL_H, 2[TABLE_LABEL]  ;MAP_PW table label
                                182
    00DC                        183   EXIT_LOCATE_VECTOR:
    00DC F0                     184      RET
                                185
                                186   PUBLIC LOOK_UP_DUMP_TIME_TB
                                187
    00DD                        188   LOOK_UP_DUMP_TIME_TB:
                                189   ;Look up solenoid dump time from calibration table, routine calling
                                190   ;convention:
```

```
ERR LOC  OBJECT              LINE       SOURCE STATEMENT
                              191   ;Xi is already in register CL and dump time table address is already
                              192   ;in TABLE_LABEL, word wide YYi is read from table and result stored
                              193   ;in AX, no interpolation is done.
                              194   ;Vector tables are in the following format:
                              195   ;       VECTOR_TABLE:   NNNN     ;= No. of break points: 1 word
                              196   ;                       X1       ;Xi: 1 word, e.g. vehicle speed in mph
                              197   ;                       YY1      ;YYi: 1 word, e.g. timer hex counts
                              198   ;                       Xi               ;i-th X break point
                              199   ;                               YYi      ;i-th YY value
                              200   ;                       Xn               ;last X break point
                              201   ;                               YYn      ;last YY label
                              202   ;
   00DD A20000          E     203       LD      DX, [TABLE_LABEL]+      ;get total no. of break points
   00E0 A00000          E     204       LD      END_POINT, TABLE_LABEL  ;get address of first break point
   00E3 0500            E     205       DEC     DX                      ;calculate address offset for last
   00E5 7D0400          E     206       MULUB   DL, #4                  ;break point
   00E8 640000          E     207       ADD     TABLE_LABEL, DX         ;starting with VECTOR_LABEL pointing to
                              208                                       ;last break point
   00EB A00000          E     209       LD      DX, TABLE_LABEL         ;record address of last break pt. in DX
                              210
   00EE                       211   FIND_BR_PT:
   00EE 9A0000          E     212       CMPB    CL, [TABLE_LABEL] ;X - Xi
   00F1 D900                  213       JH      GET_RESULT              ;get result if X is higher than Xi
   00F3 DF08                  214       JE      GET_RESULT      ;get result if X is equal to Xi
   00F5 880000          E     215       CMP     TABLE_LABEL, END_POINT  ;get result if Xi is the first
   00F8 DF06                  216       JE      GET_RESULT              ;break point
   00FA 69040000        E     217       SUB     TABLE_LABEL, #4         ;or else check the next lower break pt
   00FE 27EE                  218       BR      FIND_BR_PT
                              219
   0100                       220   GET_RESULT:
   0100 A3000200        E     221       LD      AX, 2[TABLE_LABEL]  ;get MAP_PW table label
   0104 F0                    222       RET
                              223
   0105                       224       END

ASSEMBLY COMPLETED,   NO ERROR(S) FOUND.
```

```
SOURCE FILE: A:M8256.ASM
OBJECT FILE: A:M8256.OBJ
ERR LOC  OBJECT          LINE      SOURCE STATEMENT
                            1   $TITLE("M8256.ASM: 8256 MUART monitor module")
                            2   ;M8256 - 8256 MUART monitor module, contains routines for initialization
                            3   ;of 8256 registers, receiving and sending characters to MUART, and
                            4   ;processing command received from MUART's serial port.
                            5   ;This routine is used to monitor engine sensors readings and
                            6   ;calculated pulse width during system emulation.
                            7   ;8256 REGISTER EQU'S
                            8   ;
C000                        9   MUART_CMD1              EQU     0C000H      ;8256 COMMAND 1
C002                       10   MUART_CMD2              EQU     0C002H      ;8256 COMMAND 2
C004                       11   MUART_CMD3              EQU     0C004H      ;8256 COMMAND 3
C006                       12   MUART_MODE              EQU     0C006H      ;8256 MODE REG
C008                       13   MUART_PORT1_CNTR        EQU     0C008H      ;8256 PORT 1 CONTROL
C00A                       14   MUART_INT_ENABLE        EQU     0C00AH      ;8256 INTERRUPT ENABLE
C00A                       15   MUART_SET_INT           EQU     0C00AH      ;8256 SET INTERRUPTS
C00C                       16   MUART_INT_ADDR          EQU     0C00CH      ;8256 INTERRUPT ADDRESS
C00C                       17   MUART_RESET_INT         EQU     0C00CH      ;8256 RESET INTERRUPTS
C00E                       18   MUART_R_BUFFER          EQU     0C00EH      ;8256 RECEIVER BUFFER
C00E                       19   MUART_T_BUFFER          EQU     0C00EH      ;8256 TRANSMITTER BUFFER
C010                       20   MUART_PORT1             EQU     0C010H      ;8256 PORT 1
C012                       21   MUART_PORT2             EQU     0C012H      ;8256 PORT 2
C014                       22   MUART_TIMER1            EQU     0C014H      ;8256 TIMER 1
C016                       23   MUART_TIMER2            EQU     0C016H      ;8256 TIMER 2
C018                       24   MUART_TIMER3            EQU     0C018H      ;8256 TIMER 3
C01A                       25   MUART_TIMER4            EQU     0C01AH      ;8256 TIMER 4
C01C                       26   MUART_TIMER5            EQU     0C01CH      ;8256 TIMER 5
C01E                       27   MUART_STATUS            EQU     0C01EH      ;8256 STATUS REG
C01E                       28   MUART_MODIF             EQU     0C01EH      ;8256 MODIFICATION REG
                           29
0000                       30   NULL_CHR        EQU     00
0003                       31   CNTRL_C         EQU     03
0004                       32   CNTRL_D         EQU     04
0005                       33   CNTRL_E         EQU     05
                           34   ;
                           35   ;Variable declarations:
                           36   ;
                           37   ;General purpose resgisters
                           38   ;
0000                       39   RSEG
                           40   EXTRN   RO:     WORD
                           41   EXTRN   AXL:    LONG
                           42   EXTRN   AX:     WORD
                           43   EXTRN   BX:     WORD
                           44   EXTRN   CX:     WORD
                           45   EXTRN   DX:     WORD
                           46   EXTRN   EX:     WORD
                           47   EXTRN   AL:     BYTE
                           48   EXTRN   AH:     BYTE
                           49   EXTRN   CL:     BYTE
                           50   EXTRN   CH:     BYTE
                           51   EXTRN   DL:     BYTE
                           52   EXTRN   DH:     BYTE
                           53   EXTRN   EL:     BYTE
                           54   EXTRN   EH:     BYTE
                           55   EXTRN   WATCHDOG:       BYTE
                           56   EXTRN   CHR_IO_FLAG:    BYTE
                           57   EXTRN   RECV_CHR:       BYTE
                           58   ;
                           59   ;DATA REGISTER LOCATIONS
                           60   ;
                           61   EXTRN   RPM:            WORD
                           62   EXTRN   MPH:            WORD
```

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ERR LOC  OBJECT                LINE        SOURCE STATEMENT
                                 63   EXTRN   FMS_AVE_PW:     WORD
                                 64   EXTRN   MAP:            WORD
                                 65   EXTRN   CALPOT:         WORD
                                 66   EXTRN   ACH2:           WORD
                                 67   EXTRN   THR_TEMP:       WORD
                                 68   EXTRN   COOL_TEMP:      WORD
                                 69   EXTRN   THR_POT:        WORD
                                 70   EXTRN   ACH6:           WORD
                                 71   EXTRN   ACH7:           WORD
                                 72
  A000                           73   DSEG    AT      0A000H
                                 74   ;
                                 75   ;Reserve RAM storage locations for BCD and ASCII data to be sent
                                 76   ;to 8256 for transmission
                                 77   ;
  A000                           78           BCD_DATA:       DSB     6
  A006                           79           ASCII_DATA:     DSB     10
                                 80   ;
                                 81   ;RAM storage locations for address pointer for character to be
                                 82   ;transmitted to the MUART, and the counter for the current data
                                 83   ;set being transmitted.
  A010                           84           CHR_ADDR_PTR:   DSW     1
  A012                           85           DATA_COUNT:     DSW     1
                                 86   ;
                                 87   ;Define data block size
                                 88   ;
    000B                         89   DATA_SET_SIZE   EQU     11   ;No. of set of data to be sent
    0010                         90   DATA_LABEL_SIZE EQU     16   ;No. of bytes in each data label
    0006                         91   VALUE_SIZE      EQU     6    ;No. of bytes of numerical data in
                                 92                                ;each set
  0000                           93   CSEG
                                 94   ;
                                 95   PUBLIC DELAY, INIT_8256, PROCESS_MUART_CMD
                                 96   ;
                                 97   ;PROCESS_MUART_CMD: Check the current command character received.
                                 98   ;Begin or continue to transmit a predefined set of data if the received
                                 99   ;character is a CNTRL_E.
                                100   ;Begin or continue to transmit the sign-on message if it is a CNTRL_C.
                                101   ;Abort data transmission if it is a CNTRL_D.
                                102   ;
                                103   ;Before each corresponding procedure is called, CHR_IO_FLAG bit 0 is
                                104   ;checked to determine if it is the first time the command is received,
                                105   ;and the result of this check is indicated in bit 1 of CHR_IO_FLAG.
                                106   ;CHR_IO_FLAG:
                                107   ;BIT          4          3          2          1          0
                                108   ;FLAG        ALL      APPEND     NUL_CHAR   FIRST ENTRY    NEW
                                109   ;          DONE       CHAR $       DONE     SEND_CHAR   COMMAND
                                110   ;
                                111   ;SET          YES        YES        YES        YES        YES
                                112   ;CLEAR        NO          NO         NO         NO         NO
                                113   ;
                                114   ;BIT 0 - Set by NMI service routine when a new command character is
                                115   ;received. Cleared by PROCESS_MUART_CMD routine when first entry flag
                                116   ;is set. BIT 1 - Set by FIRST_TIME_ENTRY when BIT 0 is set. Cleared by
                                117   ;TX_CHR  rountine each time a character is transmitted successfully.
                                118   ;BIT 2 - Cleared on first entry. Set by SEND_CHR routine when a NUL
                                119   ;character is encountered.
                                120   ;BIT 3 - Cleared initially, set by SEND_CHR when a '$' character is
                                121   ;encountered. BIT 4 - Cleared initially, set by ENQUIRY when
                                122   ;transmission of label and data are all done.
                                123   ;
  0000                          124   PROCESS_MUART_CMD:
  0000 B00000           E       125           LDB     AL, RECV_CHR  ;load command character received.
  0003 380005           E       126           JBS     CHR_IO_FLAG, 0, FIRST_TIME_ENTRY ;check flag,
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ERR LOC  OBJECT                LINE      SOURCE STATEMENT
    0006 71FD00          E     127         ANDB    CHR_IO_FLAG, #11111101B  ;bit0=0, indicates not first
                               128                                          ;time entry, clear bit1
                               129                                                ;to say so.
    0009 2003                  130         BR      CHECK_CHR_RECVD          ;check the character received.
    000B                       131 FIRST_TIME_ENTRY:
    000B B10200          E     132         LDB     CHR_IO_FLAG, #00000010B  ;set bit1=0 to indicate first
                               133                                          ;time entry. Clear All Done,
                               134                                          ;New Command and Append flags.
    000E                       135 CHECK_CHR_RECVD:
    000E 990500          E     136         CMPB    AL, #CNTRL_E  ;Is the command character a CNTRL_E?
    0011 D704                  137         JNE     CHK_CNTRL_C   ;If not, see if it is a CNTRL_C, or else,
    0013 280C                  138         CALL    ENQUIRY       ;process ENQUIRY command
    0015 2009                  139         BR      EXIT_PROCESS_CMD
                               140
    0017 990300          E     141 CHK_CNTRL_C:    CMPB    AL, #CNTRL_C     ;Is it a CNTRL_C?
    001A D704                  142         JNE     EXIT_PROCESS_CMD ;If not, ignore it and exit
    001C 2850                  143         CALL    SEND_SIGNON_MSSG ;If yes, send sign on message
    001E 2000                  144         BR      EXIT_PROCESS_CMD ;
                               145
    0020                       146 EXIT_PROCESS_CMD:
    0020 F0                    147         RET
                               148 ;ENQUIRY:
                               149 ;Process CNTRL_E command
                               150 ;Routine checks the First-Entry flag, if it is a first entry, the
                               151 ;beginning address of the label block is loaded into AX and the
                               152 ;transmission of label characters begins. Otherwise, the address of the
                               153 ;current data or label character will be loaded into AX to transmit
                               154 ;the character. When a $ character in the label block is encountered,
                               155 ;the routine directs the conversion of the data word
                               156 ;(specified in the DATA_REG_ADDR block and indexed
                               157 ;by the counter in CX) into BCD and ASCII.
                               158 ;and then the resulting ASCII data string will be transmitted next.
                               159 ;When a NULL character is encountered at the end of the ASCII data
                               160 ;string, the address in AX will be updated to point to the beginning
                               161 ;of the next set of label to be transmitted.
                               162 ;When the counter in CX reached the end of the data block to be
                               163 ;transmitted, Bit 4 in CHR_IO_FLAG will be set to indicate that the
                               164 ;data transmission is all done.
                               165 ;
                               166 ;
                               167 ;
                               168 ;CX counts and indexes the data register in DATA_REG_ADDR block.
                               169 ;DX contains address of data to be transmitted
                               170 ;CHR_IO_FLAG:
                               171 ;Bit      3          2
                               172 ;       Append   All-Done    Status
                               173 ;         0          0      Label or data characters being transmitted
                               174 ;         1          0     signifies the time to convert data to ASCII
                               175 ;         0          1      Finished sending a set of label and data
                               176 ;
    0021 3C0049          E     177 ENQUIRY: JBS     CHR_IO_FLAG, 4, QUIT_ENQUIRY ;exit if ALL-DONE flag
                               178                                               ;is set
    0024 39000C          E     179          JBS     CHR_IO_FLAG, 1, FIRST_ENT ;bit1=1, first entry
    0027 A30112A000      E     180          LD      CX, DATA_COUNT  ;retrieve data count
    002C A30110A000      E     181          LD      AX, CHR_ADDR_PTR ;retrieve address for next character
                               182                                   ;to be transmitted.
    0031 2006                  183          BR      PROCESS_CHR_TX ;
    0033 0100            E     184 FIRST_ENT:  CLR     CX             ;first entry, clear data set counter
    0035 A1D20200        E     185             LD      AX, #DATA_LABEL ;load address of first character in
                               186                                     ;data_label. It is the first character
                               187                                     ;to be transmitted.
    0039                       188 PROCESS_CHR_TX:
    0039 3B0007          E     189         JBS     CHR_IO_FLAG, 3, PROC_DATA  ;Check Append flag
    003C 3A000B          E     190         JBS     CHR_IO_FLAG, 2, CHECK_DONE ;Append flag is clear, check
```

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ERR LOC  OBJECT              LINE      SOURCE STATEMENT
                              191                                    ;Done flag
    003F 2876                 192          CALL    SEND_CHR        ;Append snd Done flags cleared,
                              193                                  ;continue to send label or data
                              194                                  ;character
    0041 2020                 195          BR      EXIT_ENQUIRY    ;
                              196
    0043 28D7                 197  PROC_DATA:  CALL    PROC_DATA_CONV  ;Append flag is set, it is time to
                              198                                      ;convert data to ASCII
    0045 71F700          E    199          ANDB    CHR_IO_FLAG, #11110111B ;Clear Append flag to indicate
                              200                                          ;data conversion is done
    0048 2019                 201          BR      EXIT_ENQUIRY    ;exit
    004A                      202  CHECK_DONE:
    004A 0700            E    203          INC     CX                  ;increment data set count
    004C 89080000        E    204          CMP     CX, #DATA_SET_SIZE ;Is it the last data set to be sent
    0050 D60E                 205          JGE     FLAG_ALL_DONE       ;if yes, say so.
    0052 5D100000        E    206  NEXT_LABEL:  MULUB   BX, CL, #DATA_LABEL_SIZE ;or else, calculate
    0056 45D2020000      E    207          ADD     AX, BX, #DATA_LABEL  ;starting address of next set of
                              208                                      ;data label.
    005B 71FB00          E    209          ANDB    CHR_IO_FLAG, #11111011B  ;clear Done flag.
    005E 2003                 210          BR      EXIT_ENQUIRY
    0060                      211  FLAG_ALL_DONE:
    0060 911000          E    212          ORB     CHR_IO_FLAG, #00010000B ;Set All-Done flag
    0063                      213  EXIT_ENQUIRY:
    0063 C30110A000      E    214          ST      AX, CHR_ADDR_PTR ;save address of next character to be
                              215                                   ;transmitted.
    0068 C30112A000      E    216          ST      CX, DATA_COUNT   ;save data set counter
    006D F0                   217  QUIT_ENQUIRY:   RET                     ;exit
                              218
                              219  PUBLIC SEND_SIGNON_MSSG
                              220  ;
                              221  ;Send sign on message:
                              222  ;AX contains the starting address for sign on message.
                              223  ;CHR_IO_FLAG.1 indicates if it is a first entry.
                              224  ;
    006E                      225  SEND_SIGNON_MSSG:
    006E 3A0015          E    226          JBS     CHR_IO_FLAG, 2, EXIT_SIGNON  ;Check All-Done flag,
                              227                                               ;exit, if it is set.
    0071 390007          E    228          JBS     CHR_IO_FLAG, 1, FIRST_SIGNON    ;check for first
    0074 A30110A000      E    229          LD      AX, CHR_ADDR_PTR        ;entry, if not load address
    0079 2004                 230          BR      DO_IT                   ;of character to be send;
    007B                      231  FIRST_SIGNON:                          ;or else, it's first entrance,
    007B A1850100        E    232          LD      AX, #SIGN_ON_MSSG       ;load sign on message starting
                              233                                          ;address
    007F                      234  DO_IT:
    007F 2836                 235          CALL    SEND_CHR             ;send message character
    0081 C30110A000      E    236          ST      AX, CHR_ADDR_PTR     ;save address of next
                              237                                       ;character to be transmitted
    0086 F0                   238  EXIT_SIGNON:    RET
                              239  ;
                              240  ;Routine for delaying 500 msec
                              241  ;
    0087 B1FA00          E    242  DELAY:             LDB     DL, #250    ;loop 250 times
    008A B13800          E    243  DL_LOOP_0:       LDB     DH, #36+20  ;loop 36 times +20 times for slack
    008D FD                   244  DL_LOOP_1:       NOP
    008E E000FC          E    245                   DJNZ    DH, DL_LOOP_1
    0091 FD                   246                   NOP
    0092 E000F5          E    247                   DJNZ    DL, DL_LOOP_0
    0095 F0                   248                   RET
                              249  ;
                              250  ;Routine for initializing the 8256, communication parameter is set to
                              251  ;8 bit character, no parity, 1200 baud rate and 1 stop bit
                              252  ;
    0096 B10200          E    253  INIT_8256:   LDB     DL, #00000010B  ;Init 8256 COMMAND 1 to 8 bit chr,
    0099 C70100C000      E    254               STB     DL, MUART_CMD1  ;1 stop bit, 8086 mode, 16KHz
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ERR LOC  OBJECT              LINE      SOURCE STATEMENT
    009E B14700          E    255              LDB     DL, #01000111B  ;Init 8256 COMMAND 2 to No parity,
    00A1 C70102C000      E    256              STB     DL, MUART_CMD2  ;5.12 MHz clk, 1200 baud rate
    00A6 B1C000          E    257              LDB     DL, #11000000B  ;Init 8256 COMMAND 3 to enable
    00A9 C70104C000      E    258              STB     DL, MUART_CMD3  ;receiver
    00AE B11000          E    259              LDB     DL, #00010000B  ;enable receiver interrupts
    00B1 C7010AC000      E    260              STB     DL, MUART_INT_ENABLE
    00B6 F0                   261              RET
                              262  ;
                              263  ;SEND_CHR:    Routine for sending ASCII string
                              264  ;             transmission ends when character 00H is encountered
                              265  ;             address of character to be transmitted is already in AX
                              266  ;Bits 3 is set if '$' is encountered.  Bit 4 of CHR_IO_FLAG is set when
                              267  ;a NUL character is encounter.
                              268  ;Address in AX is modified in TX_CHR or in this routine so that upon
                              269  ;next ex ', AX always contains the address pointing to the next
                              270  ;character to be transmitted.
                              271  ;
    00B7                      272  SEND_CHR:
    00B7 C800            E    273                      PUSH    DX          ;Keep data in DX intact
    00B9                      274  GET_CHR_TO_SEND:
    00B9 B20000          E    275              LDB     DL, [AX]     ;Get character to send
    00BC 992400          E    276              CMPB    DL, #24H     ;Is it a '$'?
    00BF DF09                 277              JE      FLAG_APPEND  ;If so, set Append flag, or else check
    00C1 990000          E    278              CMPB    DL, #NULL_CHR   ;if it is a 00?
    00C4 DF0D                 279              JE      SEND_MSSG_DONE  ;If so, all done
    00C6 2811                 280                      CALL    TX_CHR        ;or else, transmit character
    00C8 200C                 281                      BR      QUIT_SEND_MSSG
                              282
    00CA 910800          E    283  FLAG_APPEND:     ORB     CHR_IO_FLAG, #00001000B ;Set Append flag
    00CD A106A000        E    284                      LD      AX, #ASCII_DATA   ;load ASCII data block
                              285                                                ;beginning address
    00D1 2003                 286                      BR      QUIT_SEND_MSSG    ;exit
                              287
    00D3 910400          E    288  SEND_MSSG_DONE: ORB     CHR_IO_FLAG, #00000100B ;Set All Done flag.
                              289
    00D6 CC00            E    290  QUIT_SEND_MSSG: POP     DX                      ;restore DX
    00D8 F0                   291                      RET
                              292  ;
                              293  ;Routine for sending a character to UART
                              294  ;AX contain address pointing to the next character to be sent
                              295  ;character to be transmitted is already in DL
                              296  ;CHR_IO_FLAG.0 = 1, indicates a new command character is received.
                              297  ;CHR_IO_FLAG.1 = 1, first entry to TX_CHR
                              298  ;It increments address in AX if transmission is successful, or else,
                              299  ;AX remains unchanged.  On exit, AX contains the address pointing to
                              300  ;the next character to be transmitted.
                              301  ;
    00D9 C800            E    302  TX_CHR:  PUSH    EX                          ;Save EX
    00DB 300005          E    303              JBC     CHR_IO_FLAG, 0, GO_SEND_CHR ;See if a new command
                              304                                                 ;character has been received.
                              305                                                 ;if not, go ahead and send char
    00DE 990400          E    306              CMPB    RECV_CHR, #CNTRL_D      ;If yes, is it a CNTL_D?
    00E1 DF14                 307              JE      EXIT_TX_CHR             ;if yes, stop sending and exit
                              308                                              ;otherwise ignore character
                              309                                              ;go ahead and send character
    00E3 B3011EC000      E    310  GO_SEND_CHR:    LDB     EL, MUART_STATUS ;See if done sending char
    00E8 712000          E    311                  ANDB    EL, #20H            ;Check TBE,
    00EB DF07                 312                  JE      END_TX_CHR          ;Buffer not empty, do not
                              313                                              ;transmit character
    00ED C7010EC000      E    314                  STB     DL, MUART_T_BUFFER  ;Send char if buffer is
    00F2 0700            E    315                  INC     AX                  ;empty increment address
                              316                                             ;pointer to point to the next
                              317                                             ;character to transmit.
    00F4 71FD00          E    318  END_TX_CHR:     ANDB    CHR_IO_FLAG, #11111101B ;clear first time
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ERR LOC  OBJECT                LINE       SOURCE STATEMENT
                               319                                        ;entry flag, AX retains address
                               320                                        ;pointing to current character
                               321                                        ;for the next transmission.
     00F7                      322   EXIT_TX_CHR:
     00F7 CC00            E    323                  POP     EX            ;restore EX
     00F9 F0                   324                  RET
                               325   ;
                               326   ;NMI Handler Routine, service 8256 interrupts
                               327   ;MUART 8256 interrupt is via NMI
                               328   ;If a command character is received, bit0 of CHR_IO_FLAG will be set
                               329  ;and character is copied to register RECV_CHR, if no character is received
                               330   ;CHR_AVAIL_FLAG is cleared.
                               331   ;
                               332   PUBLIC NMI_8256
     00FA F2                   333   NMI_8256: PUSHF                          ;Save PSW
     00FB C800            E    334             PUSH    DX                   ;Save temp reg
     00FD 71FE00          E    335             ANDB    CHR_IO_FLAG, #11111110B ;clear char received flag
     0100 B3010CC000      E    336             LDB     DL, MUART_INT_ADDR   ;first, get 8256 int address
     0105 991000          E    337             CMPB    DL, #10H     ;reg. If 10H, then char received,
     0108 D70E                 338             JNE     QUIT_NMI     ;else, other 8256 int, return
     010A B3010EC000      E    339   GET_CHR:  LDB     DL, MUART_R_BUFFER       ;get received char
     010F 71FF00          E    340             ANDB    DL, #0FFH                ;Mask it
     0112 C40000          E    341             STB     DL, RECV_CHR             ;Save it
     0115 950100          E    342             XORB    CHR_IO_FLAG, #00000001B ;flag that a new char is
                               343                                              ;received
     0118 CC00            E    344   QUIT_NMI: POP     DX
     011A F3                   345             POPF
     011B F0                   346             RET
                               347   ;
                               348   ;PROC_DATA_CONV:
                               349   ;routine for sending data label and data string to MUART.
                               350   ;Data index count is already in CX
                               351   ;current data label is in DATA_LABEL block indexed by value in CX
                               352   ;data ASCII string is already stored in ASCII_DATA RAM location
                               353   ;
     011C                      354   PROC_DATA_CONV:
     011C A00000          E    355             LD      BX, CX   ;load data index count into BX
     011F D90100          E    356             SHL     BX,#1    ;Multiply CX by 2 to align word-wide
                               357                              ;address for indexing
     0122 A300820300      E    358             LD      DX, DATA_REG_ADDR[BX]  ;load address of data register
                               359                                            ;in DATA_REG_ADDR indexed by
                               360                                            ;BX into DX
     0127 A20000          E    361             LD      EX, [DX]         ;load data pointed to by DX into EX,
     012A C800            E    362             PUSH    AX               ;
     012C C800            E    363             PUSH    CX               ;save CX - current data set count
     012E 2807                 364             CALL    CONV_HEX_TO_BCD ;convert data in EX to BCD
     0130 282C                 365             CALL    CONV_BCD_TO_ASCII ;convert BCD value to ASCII
     0132 CC00            E    366             POP     CX               ;restore data set index count
     0134 CC00            E    367             POP     AX
                               368
     0136 F0                   369             RET
                               370   ;
                               371   ;CONV_HEX_TO_BCD: routine for converting  HEX data to BCD. HEX data is
                               372   ;                 in EX already.
                               373   ;                 BCD values are stored in BCD_DATA RAM location in
                               374   ;       decreasing order, i.e., with most significant digit stored in
                               375   ;       lowest byte location
                               376   ;
     0137                      377   CONV_HEX_TO_BCD:
     0137 A00000          E    378        LD      AX, EX          ;load HEX data to AX
     013A A100A000        E    379        LD      DX, #BCD_DATA   ;get storage location, point to
     013E 65060000        E    380        ADD     DX, #VALUE_SIZE ;highest storage byte location+1
     0142                      381   BCD_CONV:
     0142 0102            E    382        CLR     AX+2            ;zero extended to higher word of AX
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ERR LOC  OBJECT                LINE      SOURCE STATEMENT
    0144 8D0A0000          E    383       DIVU    AXL, #000AH     ;divide by 10
    0148                        384  STORE_BCD:
    0148 0500              E    385       DEC     DX              ;decrement count
    014A C60002            E    386       STB     (AX+2), [DX]    ;store remainder, least significant byte in
                                387                               ;highest storage location
    014D 880000            E    388       CMP     AX, R0           ;if quotient not equal to zero
    0150 D7F0                   389       JNE     BCD_CONV         ;continue division, or else, stop division
    0152                        390  END_OF_DIV:
    0152 8900A000          E    391       CMP     DX, #BCD_DATA   ;Is it the lowest byte storage location?
    0156 DF05                   392       JE      END_BCD_CONV    ;if yes, stop and return
    0158 A00002            E    393       LD      (AX+2), R0      ;if no, set byte to zero
    015B 27EB                   394       BR      STORE_BCD       ;continue to store byte
    015D                        395  END_BCD_CONV:
    015D F0                     396       RET
                                397  ;
                                398  ;CONV_BCD_TO_ASCII: routine for converting BCD data into ASCII.
                                399  ;                   BCD values are retrieved from BCD_DATA byte by byte
                                400  ;                   via AL, converted to ASCII code, then stored in
                                401  ;                   ASCII_DATA RAM location in decreasing order.
                                402  ;                   (i.e., most significant digit in lowest order byte)
                                403  ;
    015E                        404  CONV_BCD_TO_ASCII:
    015E C800              E    405       PUSH    EX              ;save EX
    0160 A100A000          E    406       LD      CX, #BCD_DATA   ;get BCD data address
    0164 A106A000          E    407       LD      DX, #ASCII_DATA ;get ASCII data storage address
    0168 A1060000          E    408       LD      EX, #VALUE_SIZE ;get no. of bytes of data (digits)
    016C B12000            E    409       LDB     AL, #20H        ;insert a SPACE as the leading character
    016F C60000            E    410       STB     AL, [DX]+       ;
    0172                        411  CONV_ASCII:
    0172 B20000            E    412       LDB     AL, [CX]+       ;get digit, most significant digit first
    0175 753000            E    413       ADDB    AL, #30H        ;convert to ASCII
    0178                        414  STORE_ASCII:
    0178 C60000            E    415       STB     AL, [DX]+   ;store ASCII byte
    017B 0500              E    416       DEC     EX          ;decrement byte count
    017D D7F3                   417       JNE     CONV_ASCII  ;continue ASCII conversion if not yet zero
    017F                        418  END_ASCII_CONV:
    017F C60000            E    419       STB     R0, [DX]    ;append 00H to signify end of string
    0182 CC00              E    420       POP     EX
    0184 F0                     421       RET
                                422  ;
                                423  ;       SIGN ON MESSAGES
                                424  ;
    0185                        425  SIGN_ON_MSSG:
    0185 0D0A                   426       DCB     0DH, 0AH
    0187 43485259534C4552       427       DCB     'CHRYSLER CANADA LTD.',0DH,0AH
    0190 50524F4455435420       428       DCB     'PRODUCT & DEVELOPMENT ENGINEERING',0DH,0AH
    01C0 50524F50414E4520       429       DCB     'PROPANE PHASE II - FMC DEVELOPMENT PROGRAM',0DH,0AH
    01EC 434F4E54524F4C4C       430       DCB     'CONTROLLER DIAGNOSTIC ROUTINE',0DH,0AH
    020B 5553494E47205448       431       DCB     'USING THE ON-BOARD',0DH,0AH
    021F 3832353620405541       432       DCB     '8256 MUART',0DH,0AH
    022B 5645522E20312D32       433       DCB     'VER. 1-26-1989',0DH,0AH
    023B 5072657373207468       434       DCB     'Press the following keys for options:',0DH,0AH
    0262 434E54524C2D4520       435       DCB     'CNTRL-E to transmit data',0DH,0AH
    027C 434E54524C2D4420       436       DCB     'CNTRL-D to abort data transmission',0DH,0AH
    02A0 434E54524C2D4320       437       DCB     'CNTRL-C to send sign-on message',0DH,0AH
    02C1 454E44204F46204D       438       DCB     'END OF MESSAGE',0DH,0AH,00H
                                439  ;
                                440  ;Labels to be transmitted before each set of data string
                                441  ;
    02D2                        442  DATA_LABEL:
    02D2 0D0A50554C534520       443       DCB     0DH,0AH,'PULSE WIDTH  ','$'
    02E2 0D0A454E47494E45       444       DCB     0DH,0AH,'ENGINE RPM   ','$'
    02F2 0D0A564548205350       445       DCB     0DH,0AH,'VEH SPD-MPH  ','$'
    0302 0D0A4D4150202020       446       DCB     0DH,0AH,'MAP          ','$'
```

```
ERR LOC  OBJECT                LINE        SOURCE STATEMENT
    0312 0D0A43414C20504F       447        DCB     0DH,0AH,'CAL POT      ','$'
    0322 0D0A414348322020       448        DCB     0DH,0AH,'ACH2         ','$'
    0332 0D0A544852205445       449        DCB     0DH,0AH,'THR TEMP     ','$'
    0342 0D0A434F4F4C2054       450        DCB     0DH,0AH,'COOL TEMP    ','$'
    0352 0D0A54485220504F       451        DCB     0DH,0AH,'THR POT      ','$'
    0362 0D0A414348362020       452        DCB     0DH,0AH,'ACH6         ','$'
    0372 0D0A414348372020       453        DCB     0DH,0AH,'ACH7         ','$'
                                454    ;
                                455    ;Data address location - Define the data set to be transmitted
                                456    ;
    0382 0000              E    457    DATA_REG_ADDR:  DCW     FMS_AVE_PW
    0384 0000              E    458        DCW     RPM
    0386 0000              E    459        DCW     MPH
    0388 0000              E    460                DCW     MAP
    038A 0000              E    461                DCW     CALPOT
    038C 0000              E    462                DCW     ACH2
    038E 0000              E    463                DCW     THR_TEMP
    0390 0000              E    464                DCW     COOL_TEMP
    0392 0000              E    465                DCW     THR_POT
    0394 0000              E    466                DCW     ACH6
    0396 0000              E    467                DCW     ACH7
                                468
    0398                        469            END

ASSEMBLY COMPLETED,   NO ERROR(S) FOUND.
```

Appendix 3

A Summary of Fuel System Package Configurations used in CVS Fuel Consumption Comparison Tests

Fuel System Package	Gasoline	Conventional Propane Carburetion	Conventional Propane with Oxygen Feedback	Chrysler's 1988 Propane Production	Computer Controlled Open Loop System
Carburetion System Components	Electronic Throttle Body Fuel Injection, Standard production 38mm Throttle Body	IMPCO CA300-50 Mixer, A1-16-2 Mixer to Throttle Adapter, IMPCO 300 AM 50 Air Cleaner	IMPCO CA300-50 Mixer, A1-16-2 Mixer to Throttle Adapter, IMPCO 300 AM 50 Air Cleaner	IMPCO CA225 Mixer, 38mm Throttle Body, Single Snorkel Air Cleaner	IMPCO CA225 Mixer, 50mm Throttle Body, Dual Snorkel Air Cleaner
Fuel System and Ignition System Settings	Factory Production Specifications	2.5% Idle CO, 2.5% CO at 1800 RPM WOT. No Balance Line Compensation. Gasoline Ignition Timing Schedule	2.5% Idle CO, 3.0% CO at 1800 RPM WOT. IMPCO's AFCP Closed Loop Fuel Control Processor. Gasoline Ignition Timing	1.5% Idle CO, 3.0% CO at 1800 RPM WOT. With Electronic Part Throttle Lean Mixture Control. Propane Ignition Timing.	1.5% Idle CO, 2.5% CO at 1800 RPM WOT. Optimized Gas-air Metering Valve. Optimized Fuel Metering and Ignition Control
Emissions Hardware	Production Specifications, Three Way Catalyst, Air Pump and EGR	Three way Catalyst, and EGR retained. Air Pump removed	Three way Catalyst, and EGR retained. Air pump removed	Without Catalyst, without EGR, without Air Pump	Without Catalyst, without EGR, without Air Pump

Appendix 4

Equations Used for Fuel Consumption Calculations:

Assumptions:

Propane Fuel Blend - CGSB -Grade 1

propane	92.5 %
propylene	5.0 %
isobutane	1.25%
n-butane	1.25%

F.E. (Fuel Economy) in miles per imperial gallon:

$$F.E._{indolene} = \frac{2907.5}{0.866HC + 0.429CO + 0.273CO_2}$$

$$F.E._{propane} = \frac{1879.1}{0.819HC + 0.429CO + 0.273CO_2}$$

where, HC = mass of hydrocarbons in grams/mile,
CO = mass of carbon monoxide in grams/mile,
and CO_2= mass of carbon dioxide in grams/mile.

Therefore,

$$\frac{F.E._{propane}}{F.E._{indolene}} = 0.6463 \text{ (approximately)}$$

or,

$$F.E._{propane} = 0.6463 \times F.E._{indolene}$$

The above formula was used to calculate propane fuel economy from fuel economy data computed by the emission analyzers programmed with equations for indolene.

$$\text{F.C. (Fuel Consumption) in Litres/100km} = \frac{282.4809}{\text{F.E. in miles/imperial gallon}}$$

Vehicle Energy Consumption Ratio (propane verses indolene):

$$VECR = \frac{F.C._{propane}}{F.C._{indolene}} \times \frac{\text{heating value per unit volume of propane}}{\text{heating value per unit volume of indolene}}$$

$$= \frac{F.C._{propane}}{F.E._{indolene}} \times 0.73$$

Appendix 5

CVS Fuel Consumption Comparison Test Results:

Fuel System Package	Gasoline (Indolene)	Conventional Propane Carburetion	Conventional Propane with Oxygen Feedback	Chrysler's 1988 Propane Production	Computer Controlled Open Loop System
City Cycles (litres/100km)					
Test 1	17.19	22.24	22.63	20.60	20.11
Test 2	16.24	22.30	22.82	21.00	20.18
Test 3	17.11	22.31	22.95	18.27+	20.66
Average F.C.	16.85	22.28	22.80	20.80+	20.31
VECR	1.00	0.97	0.99	0.90	0.88
Highway Cycles (litres/100km)					
Test 1	13.02	16.74	17.27	15.63	15.93
Test 2	12.43	16.66	17.32	16.08	15.62
Test 3	12.97	16.69	17.22	15.81	15.83
Average F.C.	12.81	16.70	17.27	15.84	15.79
VECR	1.00	0.95	0.99	0.90	0.90

* Vehicle Energy Consumption Ratio, see Appendix 4 for definition.

\+ Fuel consumption reading of Test No.3 was overrated because of an experimental error where the concentration of the CO_2 sample exceeded the scaling range of the analyzer during the City cycles Therefore, this value was not used in calculating the average fuel consumption.